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Vol. 6 No. 9 September 1949

ATOMIC ENERGY IN CLINICAL MEDICINE

HENRY J. KLAUNBERG, Ph. D.
Executive Editor

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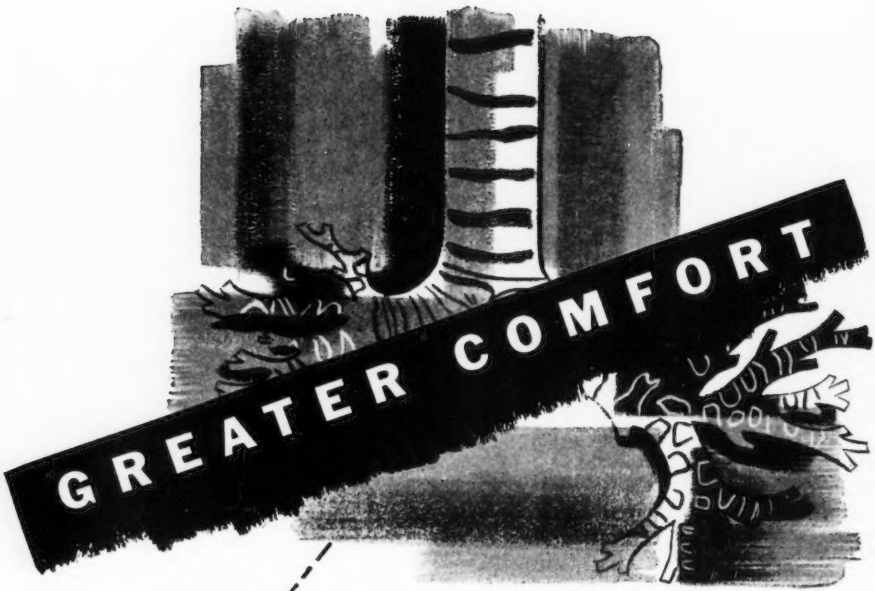

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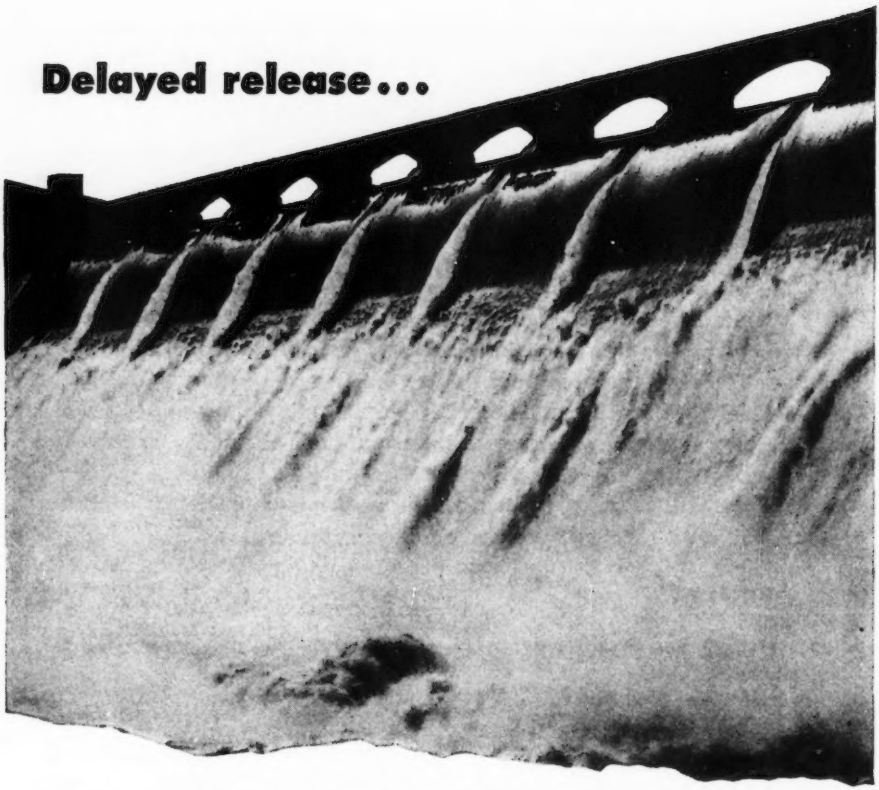

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September 1949

Vol. 6 CONTENTS No. 9

Editorial

Atomic Energy in Clinical Medicine 435
Foreword 436

1. Radiation and Life

The Growth of Knowledge 439
What is Radiation? 440
Effects of Radiation 441
Ionizing Radiation 442
Need for Basic Research 442
Pattern of This Report 443
A. Research and Living Things 444
Radiation and Living Cells 445
Damage to Tissues and Organs 447
Acute Radiation Illness 450
Acute Radiation Burns 454
B. Radiation and Heredity 456
Mechanisms of Genetics 456
Pattern of Heredity 459
A Program of Genetics Research 461
C. Analysis of Effects of Bombs on People and Areas 468
Effects of Bomb Burst in Air 468
Effects of Underwater Bomb 472
Atomic Bomb Casulty Commission 473
Long-Term Effects of Radiation 473

2. Protection Against Radiation

Record of Protection at Installations 476
Record of Protection of the Environment 478
A. Radioactive Wastes 481
Limiting Radioactivity in Wastes 481
How Wastes Are Handled 482
Improved Waste Handling 483
B. Health Physics Program 484
Types of Protection 485
Research in Health Physics 488
Research in Poisonous Materials 489

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GENERAL PRACTICE CLINICS

Vol. 6 No. 9 September 1949

ATOMIC ENERGY IN CLINICAL MEDICINE

The rapid progress in scientific research, in all fields, and the prompt application of end-results to practical use for the betterment of mankind have brought to the medical profession a succession of revolutionary advances in clinical medicine. During the past two years research in biochemistry, antibiotics, chemotherapy, antihistaminic drugs and biophysics has produced new drugs and technics that have either been demonstrated as specifics or of clinical value in the alleviation of disease entities and conditions which heretofore have proved most difficult or even impossible from a diagnostic or therapeutic viewpoint. To understand and safely and successfully apply these newer methods and therapeutic agents one must first know something of the basic structure and development of them.

As each new development has progressed from the research to the clinical stage, *General Practice Clinics* has kept its readers informed, so that they would understand, not only the clinical application of these newer methods and agents, but would also know their structures and then be enabled to adapt and apply these technics more intelligently to their own practices.

The most recent among these developments is the application of atomic energy to clinical medicine. Radioactive isotopes are now being used clinically in many ways. Therefore, the September and October issues of *General Practice Clinics* will be devoted to a presentation of the progress thus far reported and subsequent issues will report further developments so that the readers of *General Practice Clinics* will have a complete record at all times of the current status of atomic energy in clinical medicine. The clinical uses of radioactive Sodium N_{24}, iodine, phosphorus, cobalt, sulfur, carbon and iron will be presented in the September and October issues. We hope you will find these data interesting, informative and of practical benefit.

WASHINGTON INSTITUTE OF MEDICINE

HENRY J. KLAUNBERG, Ph. D., *President*

FOREWORD

The philosopher Santayana has remarked that he who feels prepared to ignore history is doomed to repeat it. In the history of scientific discovery there are lessons that the Atomic Energy Commission *is* heeding, deliberately and energetically, lest the frustrations and futilities that attended other discoveries repeat themselves in the study and development of atomic energy.

Sulphuric ether was discovered by Valerius Cordus in 1540. For over 300 years it remained a chemical commonplace, dangerously inflammable, almost unused, though employed playfully by students as a brisk and potent intoxicant. Then Crawford Long and W. T. G. Morton in 1842–44 found and showed its wonderful value as an anesthetic. It may take long years to make a substance that is known to science useful to man. Think of the sum total of unnecessary pain during 300 years of the failure to explore the effect of ether on man. Once a new substance is made, or a new process invented, years—even centuries—may elapse before all its properties or uses have been discovered and put in practice.

Roentgen discovered X-rays in 1895. The immediately obvious application in the detection and correction of fractured bones was made rather promptly. In 1902 Cannon, by using X-ray photographs of barium swallowed by experimental animals, defined one of the effects of strong emotions on the stomach and intestines. He thus laid one of the foundations for psychosomatic medicine—a far cry from classical physics. Still later in the use of hard X-rays upon tumors and soft X-rays upon the skin and hair, physicists and physicians found uses of X-rays not dreamed of by Roentgen or his contemporaries. The uses a new substance may possess are as unpredictable and as yet as certain as the future shape of a tree lying invisible in its seed.

Gasoline—at first a worthless and dangerous byproduct of distilling kerosene from crude petroleum—was thrown away by the millions of barrels, until its value was shown when used in engines designed to turn its explosive energy into mechanical work. As both result and cause of developments of the internal combustion engine, came the automobile, the tractor, and the airplane—long after gasoline was first produced and thrown away.

However, with energetic and alert study the gap between a discovery and its major application may not last long. Only 14 years elapsed between Fleming's discovery of the antibiotic effects of a common mold and the production of penicillin in significant quantities for use in human therapy.

But we cannot safely overlook the possibility of danger lurking in any activity that leads to discovery. Research experiments may create substances or unleash forces so powerful in their effects on living tissues that investigation of their properties is no idle curiosity or speculative diversion. It is an impelling necessity. We cannot afford to be casual or careless. The appalling burns from the ignorant and casual use in the early days of X-rays and radium stand on the record as a sombre warning.

If scientific research offers unimaginable opportunities for good, it imposes unexampled obligations to protect ourselves against equally unforeseeable dangers. Thanks to examples (from other fields) of wasteful waiting and reckless inadvertence, the Atomic Energy Commission is devoting extensive and unflagging attention to the biological and medical effects of radiant energy—both those that may prove to be beneficent and those that may maim or kill. When man first discovered fire he began a long apprenticeship to caution in dealing with what is both useful and dangerous—and the end is not yet.

The story of the Garden of Eden and the myth of the Promethean fire find uncanny parallels in the huge responsibilities of the Atomic Energy Commission to control the unprecedented forces of atomic energy for the welfare of man. To control the use of this power, to explore its nature, its implications and potential applications, and at the same time to protect us all against its dangers—these responsibilities set a series of tasks that also are without precedent and all but immeasurable.

The Commission is charged by law with the exclusive control of materials, equipment, and processes which are unique, constantly dangerous, and certainly not yet sufficiently understood. To this task is added the difficult circumstance, foreign to most other scientific enterprise, of secrecy. Therefore, the Commission has every reason to assume extensive responsibilities for the further development and study of atomic energy and its products and their effects on human beings, animals, and plants. The principal activities in meeting these responsibilities and hastening the discovery and application of useful substances and processes may be listed as follows:

(*a*) The health protection of personnel engaged in the preparation, transport, use, and research on the use of fissionable material and its products.

(*b*) The study of the effects on human, animal, or plant tissues of atomic bombs used in the war and in tests made subsequently.

(*c*) In view of the known sensitivity of cells at the time of their division, the study of the effects of various types of radiant energy on the processes involved in heredity, and the study of the effects of radiant energy on abnormal cell reproduction, e. g., cancer.

(*d*) The preparation of tagged atoms or isotopes for the purpose of biochemical studies not otherwise related to radiation effects, and the study and use of isotopes where these are directly related to the biological or medical consequences of radiation.

Perhaps the kernel of the situation lies in the fact that the greater man's knowledge of the laws of nature the more substances he can create that have never actually been found in nature. We can thus not only make completely unfamiliar substances but also release forces that in quality or intensity are not to be found in the natural world. Virtually a second world for study and exploration comes thus into being as a result of profoundly understanding the laws that govern the phenomena of the world about us—the first world we studied and explored. Nor is this the end of the possibilities before us. There is almost an infinity of possible applications of new substances and new forces. Indeed the case for finding the uses of new substances for human needs, the harnessing of new forms of energy to serve human purposes, rests in the phrase of Protagoras the Sophist: *homo mensura*—"man is the measure of all things." And what is to measure the needs and purposes of man?

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1. RADIATION AND LIFE

Atomic energy is not a new thing. Long before man existed, the radiation of cosmic rays—a form of atomic energy—was striking down upon the earth from the skies; radioactive elements like radium in the earth itself gave off their radiation—another form of atomic energy. This radiation from sky and earth still goes on everywhere in the world. It is least at sea level, one-tenth as strong, for instance, as in the Colorado Rockies where thinner air lets through more cosmic rays and radioactive deposits exist in the earth.

Atomic energy is not new, but never before have there been so many sources of radiation, nor has it been released at so rapid a rate. In the earth, radiation is released slowly by the gradual disintegration of some 16 elements which, like radium, are normally radioactive. Man has added enormously to the numbers of radiating substances by creating new radioactive varieties of almost all elements, and he also has increased enormously the amounts of radiation from other sources. Man has concentrated radium, has created X-ray machines, atom-smashing machines, and nuclear reactors. In the nearly 50 years that man has known about radium, for example, he has extracted no more than a few pounds in the entire world—but one reactor generates as much radiation as would several hundred *tons* of radium.

In addition to increasing the amount of atomic energy and the number of sources, man is finding new and extensive uses for radiation, and is bending all efforts toward discovering even more ways to employ it for the benefit of human kind. More and more people are coming into contact with these radiating materials: when scientists use radioactive materials as "tracers" to probe into the formation of metals and alloys, and into the hidden processes of plant life and human life; when physicians use these same materials to investigate, to diagnose, and to treat disease. Science, medicine, and industry, all are using atomic energy. Above all this is the possibility that man may again be forced to employ or defend himself against atomic weapons in warfare.

It is clearly important that we should learn all that we possibly can, not only about the peaceful uses and benefits of atomic energy, but also about the harmful effects of the radiation we have set free, and how to protect ourselves from these unseen, deeply penetrating rays of energy.

The Growth of Knowledge

We have learned this lesson of self-protection slowly and painfully. The first X-ray burn was reported in 1896. But before there was

general recognition of the danger in 1915, scientists had died from the deeper effects of X-ray and radium, and many more people were injured by X-rays in hospitals during the First World War. Strange stories went the rounds—that radiation was stimulating to the body; false stories, but people believed them. So, in the 1920's a tonic water containing minute amounts of radium was sold at fantastic prices as a miracle cure-all. People died lingeringly and painfully from drinking that water. Others, still alive, are suffering from bone diseases that may prove fatal.

In a factory, workers painted on clock dials the luminous numbers that could be seen in the dark. Following immemorial custom, the painters pointed the delicate brushes with their lips—and swallowed minute quantities of radium. Nearly a score of them died.

This damage was caused by radiation, but even more it was caused by ignorance.

The Atomic Energy Commission has the clear responsibility to inform people, not only about the progress made in promoting the national defense and security through the production and improvement of atomic explosives and weapons, but also about the benefits and the dangers of radiation. In this report, therefore, the Commission reviews the activities in biology, medicine, and health physics—which is the technique of protecting people and animals against radiation—and attempts to outline what has been learned and what accomplished in these fields.

What Is Radiation?

In atomic energy work, we are concerned basically with *high energy radiation.* A stove radiates heat; an electric bulb radiates light and heat. But these are weaker forms of radiation. High energy radiation, in the sense that we discuss it here, is the same thing as atomic energy, the same thing as radioactivity. High-energy radiation comes from the core, the nucleus, of the atom.

All material things—the human body, an electrical wire, a chair, water—are composed of certain basic constituents which we call *elements.* Iodine is an element, copper is an element; water is composed of two elements, oxygen and hydrogen; table salt of two others, sodium and chlorine. These elements in turn are composed of very minute particles called atoms. Once people thought the atom was the smallest bit of matter, but now they know that the atom itself is made up of outer shells of *electrons* which revolve about the nucleus of the atom, and that the nucleus, too, is made up of particles—mainly *protons* and *neutrons*—which are held together by a store of energy.

When we set this energy free by splitting the atom, or when we jar loose these particles from their normal orbits, we release high energy radiation.

All high energy radiation has the same kind of effect on living cells and living tissue. Some forms of radiation may cause greater amounts of damage. but the type of injury is the same.

Basically, this report will discuss five classes of radiation that are most frequently encountered in biological and medical research:

(*a*) *Alpha particles*—large, highly damaging, positively charged particles. They are unable to penetrate the unbroken skin but if an element liberating them is deposited within the body they may cause extreme damage.

(*b*) *Beta particles*—moderately damaging, moderately penetrating, negatively charged particles. They will go through about a third of an inch of tissue.

(*c*) *Gamma rays*—highly penetrating. They are less damaging, quantity for quantity, than the above types of radiation.

(*d*) *Neutrons*—uncharged, high-speed, penetrating, highly damaging particles. Depending on their speed, they can penetrate several feet of tissue.

(*e*) *X-rays*—similar to gamma rays, but less penetrating.

Effects of Radiation

These kinds of radiation affect all living things in basically the same way. This is because all living things are formed of very much the same materials.

Carbon, for example, is a constituent of all living things. The nucleus of a carbon atom carries six units of *positive* electricity. Whirling about the nucleus and forming the atom's outer shell are six electrons, each bearing a *negative* unit of electricity. The combination of these equalizing electrical units—six positive, six negative—makes the carbon atom as a whole electrically balanced and neutral. This electrical balance, this equalization of positive and negative charges within the atom, is characteristic of all atoms—of hydrogen, nitrogen, and oxygen as well as carbon. Living things use atoms of these elements to build the protein molecules which are the major constituent of their tissue, and these molecules, too, are exactly balanced. The negative charges of their thousands and millions of electrons exactly equal and balance the positive charges in the nuclei of their atoms so that the molecule as a whole is neutral electrically.

In the rapid and continuous processes of life—in the building up and breaking down of tissues, the replacement of nutrients and removal of wastes, the production of muscular energy, the reproduction of the whole organism—these complex living molecules break up and recombine in a million ways. Yet always, they combine in ways that preserve their electrical balance. To destroy that balance would damage or kill the living material.

This is what radiation does. Radiation attacks, disrupts, and destroys the delicate electro-chemical balance in the atoms, molecules, and protein combinations within the bodies of living things. As a result, it damages and kills the cells of which atoms and molecules are a part. If enough cells are destroyed, the whole organism—plant, animal, man—is severely injured or dies.

Ionizing Radiation

In passing through living tissue, radiation not only destroys the electrical balance of the atoms and molecules, but it breaks them into fragments which carry positive or negative charges. These fragments are called positive and negative ions, and the radiation that makes them is called *ionizing radiation.*

A positive ion will normally tend to combine with a negative ion to form a new molecule that is electrically neutral. In the living cell, if the two ionized parts of a broken molecule were to recombine within a very short time, perhaps no lasting damage would be done to the cell. The chances for this are remote, however, because intense ionizing radiation breaks down many different molecules and these multitudes of free ions recombine in haphazard ways. This not only completely disrupts the delicately organized tissue, but may also form new compounds that are highly toxic in themselves and will poison otherwise healthy tissue.

Moreover, ions impelled by collision with radioactive particles penetrate other tissue where they have an effect very similar to ionizing radiation itself.

Need for Basic Research

Unfortunately, beyond the general facts cited, we do not know the exact mechanism by which radiation harms living molecules, cells, and tissue. Much work of practical value has been done on a purely empirical, or trial-and-error, basis. Scientists know, for example, that bone marrow cells and other rapidly growing tissues are more sensitive to radiation than are brain cells, and that other kinds of tissue differ from one another in their resistance. Cancer cells are usually far more susceptible than normal tissue, and radiologists

have used this knowledge in treatment of cancer by X-ray and radium.

But we need to know much more about these processes, and much of the diversified biological and medical research sponsored by the Atomic Energy Commission points toward supplying essential information in these fields. Until we know how radiation acts in living tissue we cannot fully understand the mechanism of heredity in plants and animals; or the chemistry and mechanics of what "radiation sickness" does to people and how best to treat it; or the nature of growth; or the cause, diagnosis, and treatment of cancer.

In the last 20 years, radiologists have codified rule-of-thumb methods for working with X-rays and radium. Under the impact of the atomic energy program, with the thousand or more new radiation-emitting materials it has discovered or created, new knowledge is revising former views. Out of wider experience, for example, experts estimating the amount of radiation a man could tolerate day in and day out without suffering injury have revised the standard to provide an even greater margin of safety. They have cut in half the level of radiation formerly allowed. Many research projects, at AEC National Laboratories or supported under contract by the Commission are seeking to evaluate the effects of different radiations, and to establish appropriate standards and rules. But here again, the investigators are deeply aware of a lack of basic, fundamental knowledge of the mechanism of radiation effects.

Today, research into radiation is straining the manpower and financial resources of the Nation's scientific institutions. Even so, it will be many years before even half the problems now demanding solution can be studied. The Atomic Energy Commission has attempted to look over the entire field of this research and to undertake, or to support where necessary, those projects which seem to promise the maximum advance in knowledge.

Contractors operating Commission-owned laboratories conduct such research; the Commission also contracts with private institutions for specific research projects. All this research is of the utmost importance, but the Nation depends chiefly, now as in the past, upon the independent private research institutions of the country, supplemented by published results from abroad. This report's survey of the Commission's program ranges over the greater part of the field of basic research in biology and medicine.

Pattern of This Report

In the following sections, this report attempts to estimate how much basic research is vital to the atomic energy program. The first subsection (*A*) of this chapter describes research on the chemistry of

living things, the effects of radiation on living cells and tissue, organs of the body, and the body as a whole. The next subsection (*B*) describes research into the effects of radiation upon the mechanism of heredity in living things and upon the processes involved in heredity. Subsection (*C*) tells the results of analysis of bomb effects at Hiroshima and Nagasaki and of biological surveys at Bikini and Alamogordo 2 and 3 years after atomic bomb tests there.

Following these sections, this report will discuss (*Section 2*) methods for protecting people from the effects of radiation and review results of research to this end, of the handling of radioactive wastes from atomic energy plants and other sources so that they will not be dangerous to people, and (*Section 3*) the benefits to mankind from using radioactive materials as "tracers" to study what goes on chemically in our cells and in our blood, and the use of radioisotopes to diagnose and treat disease.

The Congress has indicated its desire to have the Atomic Energy Commission determine the application of atomic energy and its products to the study and treatment of cancer. Section 3 (*C*) will give a summary of the Commission program in this field. Section 3 (*D*) will deal with what radiation research can mean to agriculture and related industries. Section 4 outlines the AEC program for biology and medicine. *(Sections 3 and 4 will appear in the October issue.)*

A. RESEARCH AND LIVING THINGS

Since all living things are made up of molecules, and since radiation apparently can damage any molecule, the effects of radiation on life are varied and extensive. Some injuries, such as skin burns, seem relatively simple, but repeated damage of this kind can result in cancer, and the way in which this happens is a mystery. Other radiation damage is much more subtle. Gamma rays or neutrons striking deeply within the body—or the particles emitted by radioactive elements accidentally taken into the body—may prevent the production of the blood cells, or damage the bowels or the reproductive organs. Radiation most certainly can alter the functioning of the complex protein molecules called enzymes which govern and assist a thousand biochemical activities in our bodies such as digestion and the use of food energy for muscular work and for growth and renewal of tissues.

These are secrets of living things, of the dynamic changes that take place within living creatures. Through the years, science has been unable to penetrate many of these secrets because it lacked the tools and the techniques, for getting at life processes within the body.

The atomic age, which brought new and urgent reasons for investigating the subtlest of life processes, also gave us a new and powerful tool for their study—the radioisotope used as a *tracer*. Radioactive forms of elements normally used by living creatures can be "traced" through their tissues and through intricate chemical changes because their radiation can be spotted by using counters or photographic film sensitive to their rays. For many studies, this is the only tool that will permit scientists to observe the behavior of body chemicals.

Radiation and Living Cells

To understand fully the effects of ionizing radiation upon the living creature, we must understand not only the shattering effect it has on body chemicals—breaking atoms and molecules into positive and negative ions—but primarily the effect of ionization upon the living cell in which the damage takes place. All living things are constructed of cells, from the single-cell bacillus to man with millions on millions of cells.

Cells are various enough in their size, shape, and behavior to accomplish all of the manifold functions of all of the plants and animals that populate the earth. Yet all cells are constructed according to the same plan. The spore of the fungus and the egg of a hen both reproduce their kind according to the same principles and the same basic mechanism. Within the body of a man or dog, the small rapidly reproducing cells of the blood bear no external resemblance to the thread-like, long-lived cells that send messages along the nerves. They do not look like the muscle cells that provide mechanical energy—or, for that matter, like any of a thousand other special types. Yet all these cells contain the same elemental materials, arranged in the same basic pattern. Radiation can damage all of them by ionizing the molecules of which they are made.

The basic cell consists of an outer membrane holding a jelly-like material called protoplasm within which floats a denser mass of material, the nucleus. During the 300 years since the invention of the microscope, men have learned a good deal about the cell. They have observed how, by reproducing itself, it brings about the birth and development of living things, how it provides for the growth, repair, and nourishment of body parts.

The protoplasm and other materials within cells all contain *proteins*—giant, organic molecules built up of smaller units known as *amino acids*. Scientists have found some 20 kinds of amino acids in proteins, combined in varying proportions and sequences as dominos are arranged in domino games. Since there may be several hundred

amino acid units in a single protein molecule, the possible kinds of protein molecules may reach astronomical numbers.

Proteins are, in many respects, the key chemical compounds out of which living things are built. They form 60 percent of the dry weight of human bodies. Each species of living things has a unique assortment.

Life Chemistry as a Key

The biochemical study of proteins, the materials in cells mainly damaged by radiation, therefore gives one of the best approaches to a study of radiation effects upon living things.

Under contract with the Commission, biochemical research is under way in all Commission-owned laboratories and in many others. At Argonne National Laboratory, biochemists recently found that the enzymes most sensitive to radiation are those which contain a sulfur and hydrogen link and hence are most easily oxidized. Further studies are attempting to relate this enzyme reaction to the sensitivity of the cell itself and to changes that occur in the body after radiation.

Oak Ridge National Laboratory is conducting systematic investigation of the physical changes caused by radiation in certain basic elements of cells—nucleic acid and nucleo-protein. ***(The importance of these materials, almost literally the basic substance of life itself, will be discussed in the next issue).*** Scientists have demonstrated that X-ray exposure makes marked changes in the shape and size of these complex nucleic molecules and causes a pronounced fall in the amount of nucleic acid within the nucleus. Even when radiation does not kill the cell, it impairs the cell's ability to live in a normal fashion. Scientists traced this impairment to changes in the nucleic acid, and related the degree of damage to various X-ray dosages.

At the Radiation Laboratory of the University of California, Berkeley, scientists have shown that radiation definitely slows up formation of nucleic acid even in parts of the body far away from the spot that has been exposed to radiation. This supports a theory held by some radiobiologists that when tissue is irradiated it forms a new chemical substance, which might be called "X." This X in turn reacts with normal tissue that has not been exposed to radiation and causes additional effects.

Investigators at Argonne have been studying what happens to nucleic acids in single-celled animals exposed to radiation or treated with radioactive isotopes. They are also studying the genetic results of the treatment, since hereditary factors are closely tied up with these substances in the cell nucleus.

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Needle-Beam Radiation

At Oak Ridge and at the Massachusetts Institute of Technology, scientists are taking up enzyme chemistry and other protein studies. At the University of Chicago, biologists hope to learn exactly what parts of a cell are most sensitive to radiation by focusing an incredibly tiny beam upon a small part of a cell under direct microscopic observation. An average animal cell is about one twenty-five-hundredths of an inch in diameter—smaller than the point of a sharp needle. A beam sufficiently small to focus on only a part of a cell and leave the rest untouched, must be even tinier—with a diameter not more than one-tenth the size of the cell, or one twenty-five-thousandths of an inch. Scientists believe that they will have a machine capable of producing microbeams of this size, ready to begin irradiating parts of cells in about 12 months.

Research at the College of Physicians and Surgeons, Columbia University, demonstrates the use of radiation as a tool for increasing our knowledge about the delicate sheaths which surround nerves. For these studies the long, unusually large nerve cells of the giant squid are used. Currently, the Columbia scientists are trying to find out how much radiation lowers the ability of the cell's outer sheath to keep damaging ions from penetrating into the nerve tissue, and to keep essential materials from leaking out.

Damage to Tissues and Organs

Interpreting and extending their findings about radiation damage to cells and their parts, scientific laboratories are seeking to determine the gross effects of radiation on blood, tissue, and body organs, and ultimately upon such things as growth and length of life in plants, animals, and man. These studies may help indicate treatments for radiation sickness.

Workers at Argonne have studied cell growth in the liver of the higher animals by planting microscopically small, highly radioactive beads in the organ. These workers also are studying tissue outside the body in glass jars, and placing the reproductive portions of cells under electron microscopes to see how radiation affects them. Because of its ability to regenerate after radiation injury, the liver is an excellent organ for studying this aspect of growth.

Other workers at Argonne have found that among the white blood cells most seriously damaged after heavy dosages of radiation are those that fight infectious germs in the body. This finding has led physicians to inject penicillin into patients exposed to heavy radiation in order to combat infections.

The Argonne research men also found that when radiation reduced the ability of the bone marrow of some experimental animals to produce red cells, other organs, particularly the spleen, took over a part of this work.

Test for Radiation Injury

Because Oak Ridge research discovered so many changes in the blood of irradiated animals, scientists there concluded that radiation affects a number of different chemical or metabolic systems. In laboratory animals, the chloride in the plasma of the blood rose abruptly about 3 days after they were irradiated and stayed high for about a week. The amount of protein in the blood declined somewhat, and an abnormal substance, probably a fat, appeared and remained in the blood for weeks. The scientists are attempting to correlate these changes in blood with damage done to specific organs in the hope that ultimately simple blood tests may quickly give a measure of the extent of damage done to people exposed to radiation. As it is now, the physician can make his estimate only on the basis of what happens with the passage of time. At the University of Michigan, biochemists are attempting to work out a blood test, similar to a test for syphilis, to diagnose radiation injury.

Resistance to Radiation

Investigators at the Brookhaven National Laboratory, working with rats, are studying the effects of whole-body irradiation upon the functioning of the endocrine glands—those glands that secrete vital chemical substances into the blood stream. They have placed tiny lead shields around the adrenal gland and discovered that rats so protected lived significantly longer after irradiation than the unprotected rats. Next they will try the effects of irradiating the adrenal alone, using radioisotopes internally and shielding the surrounding tissue. They are also studying radiation effects on the concentrations of ascorbic acid (vitamin C), cholesterol, esters, glycogen, and other body chemicals. They expect that increased knowledge about these effects will lead to improved treatment of radiation sickness in humans.

Other investigators, using rats and mice, are attempting to determine whether animals can build up any resistance to radiation. After exposure to radiation, some animals with immunity to certain infectious diseases fare better than others that lack this immunity. Mice injected with adrenal and female sex hormones before exposure to radiation survived better than others because the injections helped build up certain white blood cells. Female sex hormones protected animals

when given a week or 10 days before radiation. Apparently, this hormone causes an overproduction of white blood cells which helps the body resist radiation damage.

At the University of Oregon Medical School, scientists injected mice with proteins from other animals and found that deaths after radiation were significantly reduced. At Argonne, scientists injected an amino acid called cysteine. They found that, when given an hour before irradiation, cysteine helped the mice resist injury; but that if it were administered after irradiation, the amino acid did not help. The investigators believe this indicates that radiation damage occurs at once, even though serious symptoms may not develop until later.

Studying Blood in a Bat's Wing

At Argonne, scientists studied the effects of radiation on circulation of blood in the wing of a small bat. The wing is thinner than tissue paper—about one-thousandth of an inch thick—so that investigators can observe change in the blood and lymph flow directly with a microscope of very high power. They found that, after the bat was exposed to radiation, the circulation of the blood slowed down, largely because broken cells and other organic debris clogged the capillary blood vessels. They have also studied the causes of hemorrhages in acute radiation cases and found that a substance like *heparin*, which normally prevents blood from clotting in the blood vessels, increased after radiation and contributed to bleeding. Two chemicals, toluidine blue, and protamine, were found to check bleeding by neutralizing the substance.

At Union College, some 1,400 mice have been used to study the effects upon growth, length of life, and blood, by irradiation with a particle accelerator or X-ray. The University of Denver is studying the effects on blood-forming and endocrine systems by using radiocobalt (cobalt 60) to irradiate individual body organs. Radioactive material is applied directly to the sex glands of rats to give information on the amounts that affect the reproductive system enough to cause noticeable changes in the physical characteristics of offspring.

At Argonne, scientists testing the effect of environment on radiation victims, kept frogs chilled after a fatal dose of X-ray. The chilled frogs survived for many months, but when removed to room temperature they died. Scientists had thought that, while living on borrowed time, the chilled frogs might escape death by building up their bodies while the cold held off the developments that follow radiation damage. Apparently, however, chilling delayed processes of repair just as much as it did the damage by radiation, and thus merely delayed death. However, in patients who have suffered radia-

tion burns to only a part of the body, refrigeration has been used to allay harmful effects. Los Alamos Scientific Laboratory also has experimented in this field.

10,000 Radiation-Treated Patients Studied

In seeking to determine the results of radiation on man himself, physicians will reexamine the skin of 10,000 persons who have received radiation treatment for noncancerous skin conditions within the past 12 years at the New York Skin and Cancer Clinic, Bellevue Medical Center. They will search primarily for possible X-ray damage and for skin cancers. To establish a "control" check on their findings, physicians will also examine some 10,000 clinic patients who had no X-ray treatment.

Acute Radiation Illness

All of these scientific investigations—into the cells and their proteins, into the components of the blood, into tissue and organ damage—will assist in efforts to protect people against radiation injury, as well as in understanding the basic biochemistry of the body. They will especially assist physicians in understanding, and in treating the illness known as *acute radiation syndrome*—the medical term for the injuries, the sicknesses and malfunctions a man suffers after his whole body has been exposed to a heavy dose of ionizing radiation such as is given off by an atomic bomb burst.

Acute radiation syndrome indicates an acute illness which may end in death or recovery of the patient after a few weeks, or it may result in chronic illness which may be fatal after a prolonged period.

The acute syndrome differs radically from previously known types of radiation injury—such as chronic radiation illness which arises after repeated or continuous exposure to radiation and gradually develops as a lingering illness. Radiation injury to a part of the body may be either acute or chronic, as when burns or ulcers result from misuse of X-ray machines. The ulcerated cancers of the skin which developed on the hands of the old-time radiologists and radium technicians are typical examples of the chronic ailments from this type of injury.

Causes of Acute Syndrome

The acute syndrome indicates a much more extensive and severe ailment than any other of these radiation illnesses. It can be caused by heavy radiation from outside the body, or by a much lesser amount of radiation from certain radioactive substances taken inside the body.

External. A man can suffer an acute radiation syndrome by being exposed to radiation from an atomic explosion, from an unshielded nuclear reactor, from a large quantity of radioactive material, or from an X-ray machine operated too long or at too high energy. If the radiation comes from outside the body, it will produce the acute syndrome only if the rays or particles are penetrating enough to strike deep into the body and damage such sensitive tissues as the marrow of the bones. Fast neutrons can do this, so can gamma and X-rays.

Internal. The acute syndrome can also result from a man taking into his body certain kinds of radioactive material that enter his tissues and bones rather widely and become fixed there. Even a small amount of some radioactive materials will cause as acute an illness as exposure to the radiation from an atomic blast.

The rays or particles also need not have great power of penetration because the material that gives them off already is deep within the body where it can do the most damage. Plutonium, for example, gives off alpha particles which can pierce only a few thousandths of an inch of tissue. But because plutonium lodges in the bone and stays there, it can destroy the marrow that manufactures red blood cells. Similarly, other radioactive materials that lodge in peculiarly sensitive parts or organs of the body can cause severe injury.

Unique Aspects of Radiation Injuries

Heavy exposures to either kind of radiation cause a massive breakdown of the body's tissues, particularly in certain organs of the body. Since destruction of cells in various tissues reaches its height at different times after exposure, symptoms from these injuries will occur at different times as the illness grows worse. Two features make this type of body damage unique:

Tissue damage. No two organs or tissues of the body suffer exactly the same amount of damage. Lymphoid tissue, bone marrow, the sex organs, and the lining of the small intestine suffer heavy damage. Muscles, nerves, and fully grown bone are not so easily injured. Other tissues, such as skin, liver, and lung, lie in between these extremes.

Delayed tissue death. Unless the radiation has been extremely heavy, cells may not die for hours or days. For a week after skin is injured by X-rays, it may show only a surface reddening and swelling of the underlying tissues. Blistering and loss of dead skin may be delayed for 2 weeks.

Varying Severity of Illness

A man suffering from acute radiation illness may have only a few symptoms, real enough to him but undetectable by the doctor. Or he may have a severe general illness that ends in death or in a long convalescence. The total amount of radiation he suffers is, of course, the thing that makes the greatest difference. Other factors that play a big part include:

The dose rate. A heavy dose of radiation delivered at one time will cause much more damage than the same dosage divided up and administered at intervals. A certain degree of tissue recovery may take place in the intervals between such periodic doses.

Type of radiation. Neutrons and alpha particles are more damaging to tissue than are gamma or X-rays, although the nature of the injury is very similar in each case, and alpha particles do not penetrate.

Individual response. Scientists believe some people have more resistance than others to radiation. This is rather definite where small amounts of radiation are concerned and may be true of the dosage necessary to cause death. Laboratory tests have proved, for example, that a dosage of radiation ordinarily fatal to man will kill 8 percent of a certain very pure strain of mice. To kill all the mice, it was necessary to more than double the dosage. Similarly, with lighter radiation, it was found there was a dosage that would kill none of the mice. As radiation increased, larger and larger percentages of each group of mice died.

Course of Radiation Illness

The course of illness in acute radiation syndrome can be described from the case records of a few people injured in radiation accidents, and of Japanese exposed to atomic bombings, where their injuries were uncomplicated by blast damage or flash burns. Only a small percentage of the Japanese in Hiroshima and Nagasaki suffered from radiation illness alone. Basing their report on these records, physicians describe the illness of a typical severely injured patient as going through four phases.

Phase I. Within an hour or so after exposure, the patient becomes nauseated, vomits, and suffers general prostration and weakness. Diarrhea may occur and his blood pressure may fall a little. In general, the heavier the dosage, the more ill the patient will be. This phase is quite similar to the "radiation sickness" suffered by patients treated intensively with X-ray or radium.

Phase II. After the first onset of the illness, symptoms tend to disappear, and for a period of a few days to several weeks the patient feels less ill. For patients who have suffered the heaviest radiation, this period will be short. Reports have stated that Japanese injured by radiation alone were entirely without symptoms during this time, but the best information is that they were sick people who, because of the emergency, drove themselves to do what had to be done.

Phase III. The illness reaches its height during this phase. Whether or not the patient survives depends on his ability to endure this acute stage. The patient becomes apathetic and develops a fever and rapid heart action. He becomes increasingly weak and loses weight. He loses his appetite, may become nauseated and suffer severe diarrhea which is sometimes bloody. Small hemorrhages may appear in the skin and the gums bleed. In severe cases, infected ulcers may spread throughout the mouth. The hair may fall from the head and body about 3 weeks after exposure.

The slightly injured recover quickly, but those who received a heavier dose of radiation may continue gravely ill for weeks. The most severely injured may grow progressively worse over a period of weeks and finally succumb, or may die within a few days.

Phase IV. Patients who survive enter a convalescence during which a feeling of weakness and fatigue are the outstanding symptoms. It may be months before the patients recover normal strength and weight. The skin hemorrhages disappear and the hair, if lost, gradually regrows. Usually within 6 months, the patient feels completely well. All usual methods of examination indicate that, by this time, the patient is normal. Even examinations 2 years later have revealed no remaining physical abnormalities. Nevertheless, it is too soon to say that survivors will not suffer further ill effects.

Other Reactions of Patients

Besides the symptoms described, the acute radiation illness includes damage that can be detected only by laboratory tests—changes in blood cells, in male sex organs, and in the functioning of other organs.

Several symptoms of the third or acute phase of the illness stem directly from injuries to certain elements in the blood. Infections and ulcerations arise because radiation destroys the white blood cells that normally hold bacteria in check. A few days after radiation exposure, the white cells decline and, in severe cases, disappear almost entirely. The skin and gum hemorrhages are seemingly connected with a fall in the number of *platelets* in the blood, since these frag-

ments of bone marrow cells help the blood to clot, although other causes such as an increase in an anticlotting substance that resembles heparin, a normal blood chemical, also contribute. Platelets begin to decline only after an interval of weeks and, where the patient survives, reappear during convalescence. A third and very serious effect upon the blood, the decline in red cells, causes anemia and contributes to the general weakness and debility so marked in acute radiation illness. The decline of red cells starts immediately after exposure and may continue for months.

Microscopic studies of tissue, amplified by more complete research with animals, indicate these blood changes are caused by radiation damage to the bone marrow and to the lymphoid tissue where these various cells are born. And the injury to tissue, as well as the course of illness in the patient, can be traced to damage to the cells. Radiation causes the cells to swell, disorganizes their structure and stops them from reproducing themselves. The stoppage of cell division occurs immediately after irradiation; structural changes appear more gradually. The most spectacular change is the collapse of certain parts of the cell, and the shrinkage of the nucleus followed by death and disintegration. The interruption of cell division is temporary, but when new cells begin again to divide they often show bizarre changes in their inner structure.

Treatment of Radiation Injuries

Scientists have devoted a great deal of experimental work to methods of treating radiation injuries. They have found no practical way to prevent the death of cells or tissues heavily injured by radiation. However, the regenerative powers of the body are very great, and if it can be helped to survive the acute stage of the illness, even the most radiosensitive tissues may be able to resume their normal functions.

Many treatments help the body through the acute stage of the illness. Blood transfusions supply red blood cells. Penicillin limits infections. Certain materials, such as toluidine blue, help to reverse the tendency to bleeding. Physicians also maintain the water and salt content of the patient's body—substances apt to be lost in any serious illness. Maintenance of adequate nutrition, especially of those substances used by the body to manufacture proteins and cells, also are helpful.

Acute Radiation Burns

Localized tissue damage, another type of acute radiation injury, presents a marked contrast to the acute radiation syndrome. In these

cases, symptoms of generalized illness are usually mild and transient. Local X-ray damage has been studied frequently. Some variations of such injuries—beta-radiation burns—have occurred recently.

At the atomic weapons test at Eniwetok in May 1948, four scientists exposed their hands to fairly large doses of beta radiation. Protective devices which would have prevented this were available, but because of the desire to complete the work quickly and also because of an underestimation of the radioactivity in the object handled, the scientists failed to use the devices.

Two of the scientists reported a tingling sensation in their hands during exposure. The hands became swollen within several hours, but the skin did not redden until after the second day. The amount of swelling and redness was proportional to the severity of the injury. Blisters began to develop on the third to the fourteenth day and grew larger until, at the fourth week after exposure, they covered the entire palms and fingers of the more severely injured persons.

Only Skin Injured

The outer one-fifth inch of skin absorbed almost all the radiation and underlying tissue suffered little damage. In this respect, beta-burns resemble injuries from fire rather than from the X-ray which damages underlying tissues. However, instead of the cells dying at once, as in the case of fire, they died gradually over a period of weeks.

The height of the reaction in each case was reached between the twenty-fifth and thirtieth day after exposure. Following this, there was loss of dead skin and gradual healing of the wounds. Ulcers that were slow in improvement followed in the severe cases.

The person with the mildest injury showed complete recovery by the fiftieth day after exposure. The skin of the injured hand was normal in appearance.

The wounds of a second scientist were completely covered by a very thin layer of skin by the seventieth day. The new skin was so delicate, however, that it broke down several months later. It was necessary in this case, and in the two other cases, to employ plastic surgery to take care of the superficial ulcerations which, although gradually healing, were still prominent 7 months after exposure. The grafted skin in these injured hands is not as sturdy as before injury, but the recovery of the use of the fingers has been surprisingly good.

All of the more severely injured scientists were under complete medical supervision, three were hospitalized; all have shown good recovery. Aside from a mild fever and a moderate increase in the number of white cells in the blood, these patients showed no signs of generalized illness. All four men either have returned, or soon will

return, to work. Their injuries will not necessitate any significant change in the type of work they will do.

B. RADIATION AND HEREDITY

High energy radiation, in addition to causing burns and radiation illness, affects living things in a more subtle way that cannot be detected so immediately or so readily. It changes the cellular material which governs heredity in people, animals, and plants, and thus alters the characteristics passed on from one generation to the next.

Not all these effects are harmful. Some, such as the changes in corn, for example, may in fact be used to improve the yield, food qualities, and disease resistance of hybrid varieties. But in an age when people are using many forms of powerful radiation in science, in medicine, in industry, in warfare, it is urgently important to learn everything possible about how radiation affects heredity.

Mechanisms of Genetics

We know that higher plants and animals develop, within the nuclei of their germ cells, tiny material units of inheritance—invisible even through a microscope—which are called *genes*. The Austrian abbot, Gregor Mendel, and his followers during the 83 years since Mendel first published his classic paper, have made this much certain. We know also that living things inherit their genes from their parents and pass them on to their descendants.

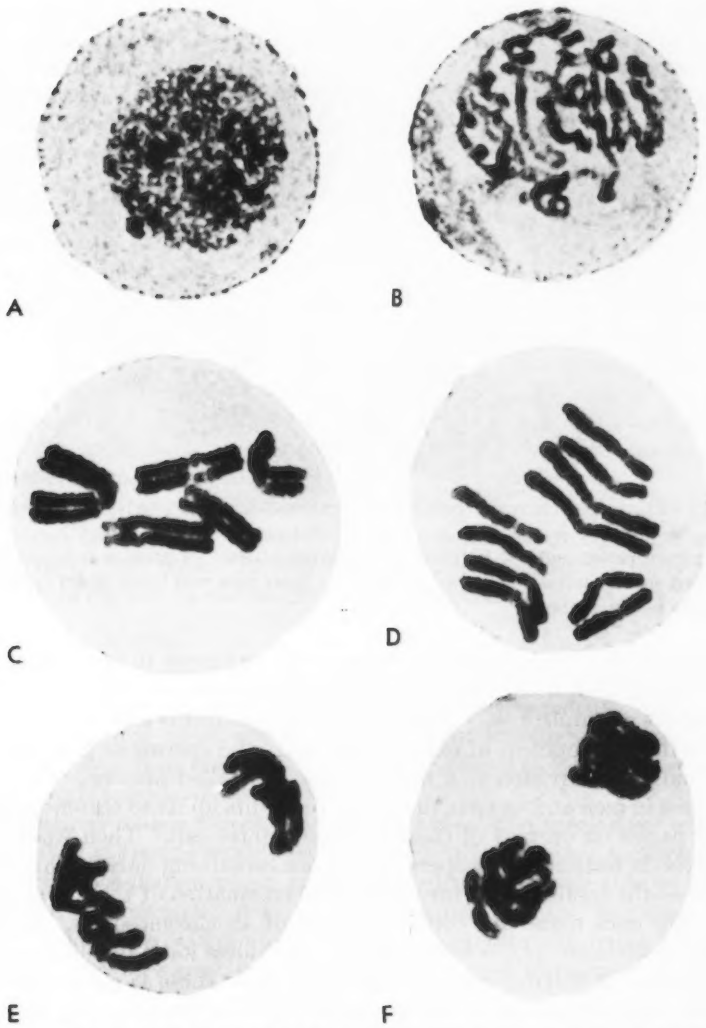
Within the nucleus of the germ cell, the genes are arranged like beads along rod-like bodies called *chromosomes*. The chromosomes vary among different plants and animals, and even at different stages of growth, but the longest of them is about one-hundredth of an inch and can readily be seen with the aid of a conventional microscope.

Each kind of plant or animal has a set number of chromosomes in its cells. Man has 24 pairs, a total of 48 in each cell of the body. The fruit fly has 4 pairs, corn 10 pairs, pink bread mold 7 pairs in certain of its cells.

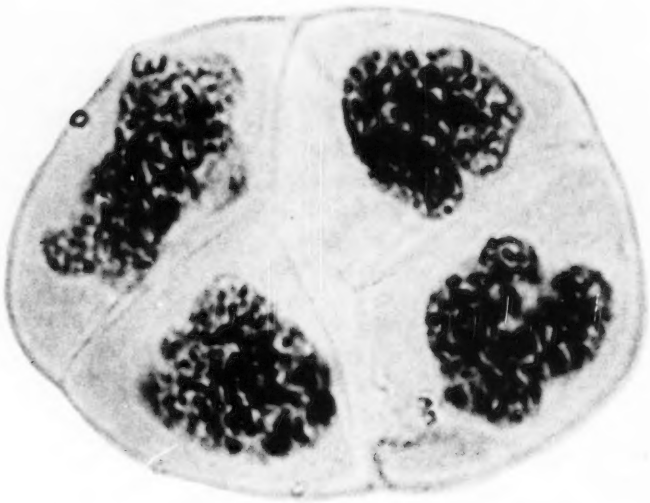
Scientists do not know the number of genes in a given organism, but believe, for example, that the cells of a fruit fly contain about 10,000 different genes beaded along its eight chromosomes, and that other higher plants and animals, including man, have about the same number of genes.

Mitosis and Meiosis

A body cell reproduces itself by a process of division called *mitosis*. In this process, the cell forms two identical sets of 48 chromosomes



Immature pollen cells of trillium plant before and during first cell division by mitosis; microphotographs from Brookhaven National Laboratory, magnified about 8,000 times. A. Cell during resting phase, showing cell membrane, cytoplasm, and dark-colored nucleus. B. First stage (prophase) of dividing cell; stringlike chromosomes begin to appear in nucleus. C. Second stage (metaphase), showing the lengthwise splitting of the chromosomes. D. Third stage (anaphase), early; divided chromosomes begin to move apart. E. Third stage, late; divided chromosomes have been drawn to opposite sides of cell. F. Final stage (telephase); chromosomes begin to lose individual identity forming two nuclei; soon the cytoplasm will divide forming two complete daughter cells.



Immature pollen cells of trillium; Brookhaven photo. Original single cell has divided once by mitosis and once by meiosis. Four cells will break apart forming mature pollen grains.

and their thousands of genes. These twin sets move to opposite ends of the cell and, when the cell divides, each of the two daughter cells possesses a complete set. (See facing photographs D and E.)

In the development of sexual cells—eggs and sperms in plants and animals—the division is a different process called *meiosis*. In this process in men and women, the sexual cell splits up its 48 chromosomes and passes on only 24 of them to the daughter cell. Then when an egg cell is fertilized by a sperm—each one containing only 24 chromosomes—the resultant cell formed by the combination of the sperm and the egg once more will contain a total of 48 chromosomes. In its further divisions as the fertilized cell reproduces itself to build a new individual, it will duplicate over and over again those 48 chromosomes which are a composite of the sets inherited from the male and female parent—24 chromosomes from the father, 24 from the mother, each carrying its allotment of genes.

Why Genes Are Important

Geneticists believe that each of the 10,000 or more genes in a human cell is unique, and that each performs a special job in the development or function of the body. They study and identify the genes through

their effects on the children. To illustrate: in man, the colors of the hair, skin, and eyes come from pigments called *melanins*. If a certain one of the thousands of genes from both parents has an unfavorable effect on production of melanin, the child's body can produce no melanin at all. As a result, the child from birth is an albino: pink-eyed, light-skinned and white-haired.

If another specific gene in both parents has an effect unfavorable to proper clotting of the blood, the child's blood fails to clot normally and he will be a "bleeder" said to have inherited the disease, hemophilia.

Albinism and hemophilia are both *recessive traits*. This means that if one parent, for example, gives a child a gene that could give rise to albinism, whereas the other parent gives a normal melanin gene, the child will not be an albino, but will be normal. To inherit the albinism, the child must receive albino-producing genes from both parents. In such cases, the normal form of the gene is called *dominant*, the other form *recessive*.

Some inherited abnormalities, however, are dominant, as in the case of "sickle-cell anemia," in which the red blood cells are abnormal and have very short lives. In this case, the disease appears if only one gene from one parent carries the unfavorable trait.

Mutation Changes

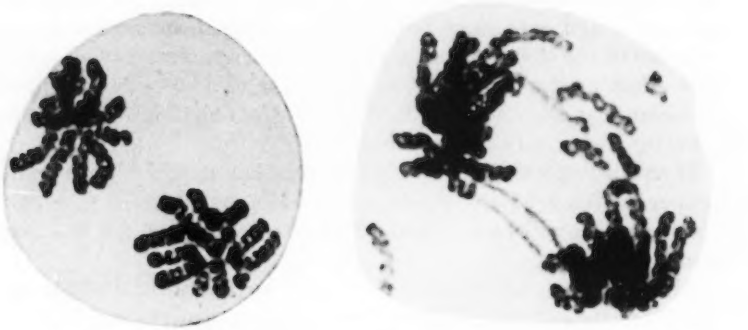
The precision with which genes normally duplicate themselves during cell division is living matter's greatest achievement. Changes from the normal which are recognizable occur less than one time in a million. But such changes do occur and they are known as *mutations*—unfavorable or favorable.

Mutations which reduce the total numbers of a species, or which reduce the vigor of individuals, are called unfavorable. A favorable mutation is a change which makes the individual better able to cope with its environment. Favorable mutations are rare, but they do occur. They are believed to be the basis of evolution in living things.

Much more frequently, mutant genes produce unfavorable effects in the organism just as random alterations would be expected to harm any complex piece of machinery. They tend to be eliminated by natural selection. In some cases the effect of the mutant factor is so harmful that it results in the death of the individual, perhaps even before birth. Such deadly mutations, of course, are not transmitted to later generations.

Pattern of Heredity

In 1926, Professor H. J. Muller, of Indiana University, discovered that the rate of mutation in the genes of the fruit fly could be greatly



Trillium germ cells during division by meiosis; Brookhaven photo. Cell at right has been irradiated, causing broken chromosomes. In the living cell this might cause death of cell, prevent further division, or cause changes (mutations) in the growing plant.

increased by treatment with X-rays. It can now be said with certainty that ionizing radiation similarly affects all living things. High-energy radiation may produce genetic effects in living cells in three ways:

(*a*) Indirectly through production of substances that have secondary genetic effects. For example, X-rays produce hydrogen peroxide, which is poisonous, in water and living cells. They also produce free ions, or electrified parts of molecules and atoms. Such free ions may recombine in different ways. Both the production of poisonous substances and the formation of free ions may have indirect effects on living systems. Recent studies have shown also that mutation rates in certain bacteria may be greatly increased by placing them in a fluid which previously has been irradiated. Substances that cause these mutations are evidently produced in the fluid by the radiation.

(*b*) Through direct effects on such organic molecules as the genes. Direct ionization of the molecules is probably the chief effect of radiation. This may result in breaking chemical bonds, which no doubt permanently alters genes.

(*c*) Through the breaking of chromosomes. Chromosome threads are about seven-millionths of an inch in diameter. Scientists have calculated that it takes only about 20 ionizations across the diameter of such a thread to break it. (See photograph above.)

When chromosomes are broken by ionizing radiation, the ends may try to rejoin and so restore the original condition. However, if more than one break occurs, the fragments may form new combinations

known as *aberrations* or *translocations* which affect heredity. Scientists know the inherited consequences of many chromosome rearrangements and use them as tools in investigations.

A Program of Genetics Research

The Commission devotes a major part of its biological research to the effects of radiation on heredity. It helps finance scientists in studies that range from the genetics of a single cell to those of large populations of higher animals and plants.

For a score of years, scientists have studied radiation effects on heredity through patient and ingenious experiments that involved hundreds of thousands of plants or animals over hundreds of generations. They have related the observed mutations to alterations in minute parts of the germ cells. However, they know little about just how radiation acts to produce the changes that result in mutations.

Scientists today are concentrating on gaining a better understanding of these mechanisms.

Pattern of Research

The basic hereditary components of germ cells—the genes—appear to be complex protein molecules not unlike enzymes. At the California Institute of Technology, Los Alamos Scientific Laboratory, and Yale University, studies supported by the Commission are gathering and analyzing facts about the biochemical effects of radiation upon proteins, viruses, bacteriophages, and other large organic molecules. At Oklahoma Agricultural and Mechanical College similar studies are under way on a nitrogen-fixing bacteria in soil. The pink bread mold is a subject of research at California Institute of Technology and at Oak Ridge, and the tiny single-celled fresh water animal called paramecium is being studied at Oak Ridge and Argonne. In the paramecium studies, scientists will seek to build certain radioactive elements—carbon, hydrogen, phosphorus, and sulfur—into the nuclei of the cells to check on a belief that this will bring about more mutations and a greater change in the characteristics of offspring.

Many classical studies on the mechanism of genetics have been made with the spiderwort plant, and this is the subject of investigation at the Oak Ridge Laboratory and Radiation Laboratory, Berkeley. At Brookhaven, the sensitivity of germ cells to radiation during the period of cell-division is under investigation. Here the common wildflower, trillium, is used.

Studies on the heredity of corn by geneticists and plant breeders during the last 20 years have developed hybrid corn, an innovation worth scores of millions of dollars a year to American farmers—and,

more importantly, a means of growing more food from each acre planted to hybrid strains. Further advance in corn breeding—and thus food production—can be made by creating new strains for the hybridizers to use in new combinations. Hundreds of mutant strains of corn irradiated at the Bikini bomb tests are now under study at California Institute of Technology. Geneticists at the University of Nebraska are experimenting with corn and corn pollen irradiated in the nuclear reactor at Argonne.

The common fruitfly breeds abundantly and rapidly so that in a few months generations equivalent to a thousand years of human growth can be observed in the laboratory. Radiation effects are investigated with experimental colonies of fruitflies maintained at Oak Ridge, California Institute of Technology, Long Island Biological Station, and Harvard University.

Fish genetics studies are under way at the University of Washington's Applied Fisheries Laboratory, as are studies of mouse genetics at Oak Ridge and University of Rochester Atomic Energy Project. The University of Tennessee has facilities to study genetics in large animals. The cattle exposed to the Alamogordo atomic bomb test are under observation there.

Human and Animal Genetics

Scientists must base their estimates of the effects of radiation on human heredity largely upon experiments carried out with such organisms as the fruitfly. They have no information about how radiation affects mutation in man and very little about what it does to the larger animals.

Investigators have determined that mutation rates seem to be of about the same magnitude over a wide range of living things, but they do not know whether this holds true for animals. It is important that mutation rates be determined as accurately as possible, because very small doses of radiation may produce a genetic change. In fact, it is questionable whether there is a dosage of radiation so weak that it does not have some effect. Some scientists believe that there is a threshold dosage below which there are no genetic effects; others believe the opposite. Investigators at Oak Ridge and Harvard University are attempting to give a definitive answer to this question.

Everyone in the world is exposed to some radiation from the crust of the earth and from cosmic rays. At sea level, for example, a person is exposed to about three roentgens of radiation in a lifetime. This is not a heavy dosage. The roentgen is a measure of the ionizing effect of radiation—the amount necessary to generate one electrical unit in a

cubic centimeter of dry air. But even this slight dosage of radiation may be one of the factors which, with chemical changes in the body, causes the mutations that occur "naturally" in people, plants, and animals. Since everyone is, and always has been, subject to such "background radiation," scientists are inclined to believe that small, weak dosages of radiation will not increase the number of mutations—fewer than one in one million births—that already occur "naturally."

Animal experiments. The first step in evaluating genetic effects in humans is to experiment with animals more closely related to man than those previously used in studies, and to estimate with them the mutation rate caused by measured doses of radiation.

The second step is to determine what increase in mutation rates can be considered "serious." This cannot be accomplished by learning mutation rates alone. We need further to know the anatomical and physiological effects of mutation. Here again, direct work on animals is necessary.

The Oak Ridge laboratory has started an extensive, long-term program of research to find answers to some of these questions. It will experiment with mice, because they produce four to five generations a year and because they are inexpensive. Cost is important, since large numbers of animals must be tested to give significant results.

Oak Ridge also is studying radiation effects on mice at various stages of pregnancy. The laboratory seeks to determine sensitive stages in embryonic development, the total effect at each stage, the order in which changes are produced, and the relation of dosage to effect. This work has far-reaching implications for human pathology.

The University of Rochester, under an Atomic Energy Commission contract, also is investigating the effect of radiation on genetics in mice.

Fish genetics. The effects of radiation on three generations of salmon and four generations of rainbow trout have been studied by the Applied Fisheries Laboratory of the University of Washington in a program currently financed in part by the Commission. These fish are particularly good as laboratory animals for genetic studies because a female produces 2,000 to 5,000 eggs in a single spawning, and geneticists can accomplish controlled external fertilization. X-raying of the fish does not damage the surviving offspring as food for other creatures.

In the work with salmon, fish about to spawn were exposed to radiation by X-ray. Eggs, when ready, were taken from the fish, artificially fertilized and, 6 months later, marked fingerlings were re-

leased into the river. On their return in 1946 and 1947, the marked fish were trapped and paired in accordance with the amount of irradiation they had received. The process was repeated, and in 1951 and 1952, third generation matings of irradiated fish will be possible, and research men can study fourth generation genetic effects and the delayed physiological results of exposure to X-rays.

In the X-ray series with rainbow trout, seven groups were given varying dosages. Offspring of trout showed deteriorating effects of that single dosage as late as the fourth generation. The studies indicate that the larger the dosage received by the first generation, the more descendants will die or develop abnormalities. However, radiation did not produce radically new types of abnormality; it merely increased the number of occurrences of mutations already known.

Other Genetic Projects

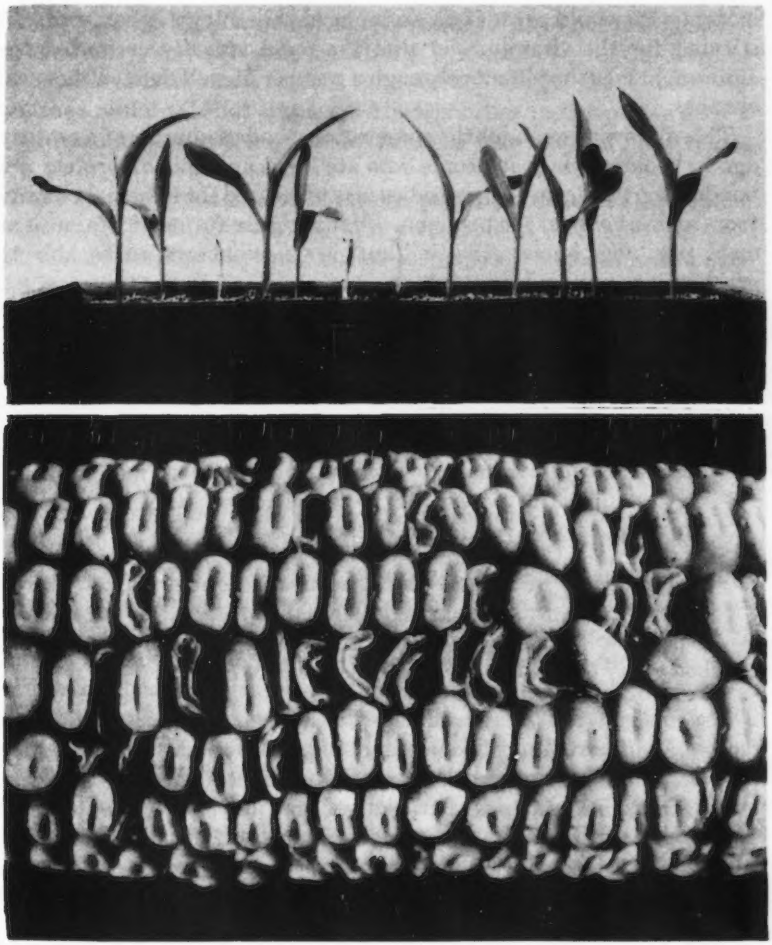
Bread mold. The tropical pink bread mold lends itself particularly well to studies on the nature of gene action. The mold reproduces rapidly by nonsexual "seed-like" bodies called spores, or alternatively it has a sexual cycle that requires about 10 days—approximately the same as the fruitfly. Different strains can be isolated and the mechanism by which genes pass from generation to generation of the mold is easily followed in the laboratory.

Moreover, the mold grows readily on a simple medium that contains ordinary cane sugar, nitrate, phosphate, and sulfate salts, and the B-group vitamin, biotin. From these foods, the mold synthesizes some 20 amino acids, 10 or more vitamins, and a host of other carbon compounds—many of them the kind of molecules out of which human bodies construct protoplasm for cells.

Scientists produced many mutant types of the mold by exposing it to strong radiation. Some mutants could not grow on a medium which nourished normal strains because in the process of mutation the mold had lost the ability to carry out certain chemical reactions. The "offspring" of the mutant mold inherited this inabiilty.

At the California Institute of Technology, several hundred mutant strains—each unable to perform one particular chemical reaction—have been produced. Spores of the mold exposed to atomic bomb radiations during the tests at Bikini and Eniwetok, gave rise to many mutations similar to those induced in the laboratory.

Reversing a mutation. Oak Ridge Laboratory investigators found that radiation could also produce reverse mutations in the mold, and restore the mold's ability to make its own vitamins, thus demonstrating that some radiation mutations improve the organism. This technique of reversing mutations also permits investigation of changes



Corn grown from seed exposed to atomic bomb at Bikini shows effects of irradiation, in tests at California Institute of Technology. Three young plants show stunted growth. Mature ear has damaged and undeveloped kernels.

in individual genes—an extremely difficult procedure. The results already obtained are contributing to an understanding of the basic mechanism of gene mutation.

Mutant strains have provided important tools for measuring the amounts of various vitamins in plant and animal tissues, and for explaining the genetic basis for chemical changes in the body. For example, one mutant strain, in order to grow, requires the vitamin niacin which prevents pellagra in humans. Scientists found that this

mutant also would grow if an amino acid called tryptophan was substituted for the vitamin, and that the mold actually converted the amino acid into the vitamin through a number of well defined chemical changes.

This discovery explains the observations made a quarter of a century ago by Goldberger that people who ate large amounts of protein did not develop pellagra. Their bodies manufactured the essential vitamin from amino acids in the proteins. Many higher forms of life, such as man, pig, dog, horse, cow, and rat, are now known to be able to synthesize the vitamin in this way.

A long step forward. Scientists have formed two important conclusions from "chemical genetics" of the kind being done with the mold:

(*a*) Geneticists believe that genes affect particular chemical reactions that enable individuals to develop and function, and probably they establish the patterns of the formation of particular enzymes which act as catalysts in these reactions.

(*b*) The genes, as well as the basic chemical reactions of many kinds of living beings, are strikingly similar and thus the influence of genes, duplicated in every body cell, upon protein patterns in the body may be a key to the mechanics of heredity.

These concepts provide for the first time a key to understanding the mechanics of heredity. The influence of genes upon heredity has long been known, but geneticists had not been able to determine how the genes accomplished their influence upon the offspring. The practical application of this discovery in basic research cannot be estimated at this time, but the more we learn about these mechanisms, the greater facility breeders of livestock and of plants will have in developing new and more favorable strains.

Indian corn. Of the higher plants whose heredity has been studied, corn is one of the best known. Plant geneticists have investigated many mutant strains, and located many of the genes related to specific changes. The 10 chromosomes of corn are relatively large and easily studied at certain stages of development, and unusual forms and sizes can be readily identified.

Seeds of corn, exposed to atomic bomb radiation at Bikini and Eniwetok, showed three types of effects: (*a*) abnormalities in the

development of the plant, (*b*) chromosome breaks and cross-linkage (aberrations), and (*c*) gene mutations. About 500 progeny lines of inheritable chromosome breaks and cross-linkages have been established and are being studied. Abnormalities in the plants grown from irradiated seed were greatest in those that received most radiation.

Such aberrations and translocations provide a new kind of genetic tool that may well prove to be highly valuable in corn breeding programs. In further improvement of corn strains, experimenters may find it desirable to transfer specific traits from one strain to another. For example, a strain may be ideal except that it is susceptible to corn smut. Another strain may be smut resistant but otherwise undesirable. An understanding of the way in which smut resistance and other traits are transmitted would point the way toward combining the desirable traits of two lines in a single strain.

Speeding up hybridizing. Using radiation to bring about chromosome translocations may greatly cut down the time and labor required to accomplish such ends in corn breeding. California Institute of Technology has a large collection of corn seed whose cells include translocated and inverted chromosomes, many derived from Bikini material. These aberrations are being transferred by crossing to standard hybrid corn and the seed will be available to corn breeders.

Investigators are using radiation-induced mutants of corn very much as they have such strains of bread mold. They found that the same amino acid-vitamin system occurs in corn, and they are studying the conversion of a part of the amino acid, tryptophan, into the plant growth hormone known as *auxin*. Previous studies of auxin led to new chemicals used by horticulturists to control the time and rate of fruit tree flowering and fruit setting, and by farmers and gardners for selective killing of weeds.

Since tryptophan, auxin, and the niacin vitamin are of such great importance in determining the value of corn grain as food for animals, it is important to learn more about how these substances are formed in the corn kernel, and how the three are related to one another. Plant scientists believe that mutant strains will be of great help in finding the answers to these important questions, and thus improving the productive power, as animal food, of each year's corn crop.

C. ANALYSIS OF EFFECTS OF BOMBS ON PEOPLE AND AREAS

Medical effects of the explosions over Hiroshima and Nagasaki were first studied by the Joint Commission of Medical Officers of the Army, Navy, and Manhattan District. Now, and for some time past, further studies are being carried out by the Atomic Bomb Casualty Commission of the National Academy of Science's National Research Council, which work is financed by the Atomic Energy Commission. Data have been gathered also on after-effects at Bikini and Alamogordo.

The AEC is financing studies of these and related problems by the Los Alamos Scientific Laboratory, the Argonne and Oak Ridge National Laboratories, the University of California both at Berkeley and at Los Angeles, the University of Rochester, University of Chicago, University of Tennessee, University of Southern California, Western Reserve University, Harvard University, Cedars of Lebanon Hospital, University of Kansas, University of Virginia, University of Denver, Washington University (St. Louis), University of Oregon, University of Michigan, University of Washington, College of Physicians and Surgeons, Columbia University (New York), and New York Post Graduate Hospital. The progress of these studies is carefully reviewed by the AEC's Advisory Committee for Biology and Medicine as well as by the staff of the division.

Of the results so far obtained in these studies, some are classified and cannot be publicly stated. There is, however, a considerable body of fact on medical effects of atomic bomb explosions which is unclassified or has been declassified. It has appeared piecemeal in the following individual documents: *The Atomic Bombings of Hiroshima and Nagasaki*, by the Manhattan Engineer District; *Medical Aspects of Nuclear Energy*, Armed Forces Special Weapons Project, 1949; *The Effects of Atomic Bombs on Hiroshima and Nagasaki*, Chairman's Office, United States Strategic Bombing Survey, 1946; *The Effects of Atomic Bombs on Health and Medical Services in Hiroshima and Nagasaki*, Medical Division, United States Strategic Bombing Survey, March 1947; and *The Effects of the Atomic Bombs at Hiroshima and Nagasaki*, Report of the British Mission to Japan.

Effects of Bomb Burst in Air

The effects of an atomic bomb vary with the method of explosion, but there are three basic types of injury produced: (*a*) mechanical, from the blast effects; (*b*) thermal, from the radiant heat of the burst

and from the fires burning in the wreckage; and (*c*) radiation, from the radioactivity released by the burst.

Hiroshima, Nagasaki, and the first Bikini test may be taken as typical of an explosion in air. At Hiroshima and Nagasaki, a majority of the deaths and injuries resulted from blast effects due to the collapse of buildings and to falling debris. Many additional casualties resulted from flash burns or secondary burns incurred in the fires that raged after the explosion. Fifty to 60 percent of the casualties were due to blast effects and flame burns, 20 to 30 percent to flash burns, and 15 to 20 percent to ionizing radiation. However, had there been protection from blast and fire, nearly as many people would have died from radiation effects alone. Death was officially attributed to the most obvious cause, either blast or burns. An individual crushed by falling concrete after being seriously burned was classed as a blast casualty, although the amount of ionizing radiation received undoubtedly would have caused death had not blast or burn injuries proved fatal.

Perhaps the most readily understandable way of describing the effects of atomic explosions is to use zones bounded by concentric circles whose center is directly below the point of explosion. The effects in these zones depend somewhat on local factors, and change gradually rather than abruptly.

Effects Within a Half-Mile Radius

Within a half-mile of a point directly under a bomb explosion—the point called ground zero—when the atomic bomb is similar to those used against Japan and detonated at a height up to several hundred feet in the air, the following will occur:

The blast pressure created by the bomb explosion will demolish all structures not of reinforced concrete or steel construction within this area. Well-constructed buildings of the latter type will suffer structural damage up to 70 percent of total destruction with severe damage to windows, partitions, walls, and contents. Persons not sufficiently protected by shelter able to withstand the blast would undoubtedly be killed by falling buildings or flying wreckage.

Intense thermal energy generated by the explosion would cause fatal burns to unprotected persons and would start fires in the wreckage. Protection against flash burns is relatively easy since either clothing or a special ointment will avoid the worst injuries.

The explosion of an atomic bomb also releases an enormous store of energy as invisible radioactive waves or particles which are highly destructive to living tissues. The various particles and rays differ in their ability to penetrate objects, such as lead or concrete, and in

their ability to penetrate the body. From the standpoint of kind of effect they have, they are similar.

Because of the concentration of such radiation within a half-mile of ground zero, nearly everyone not protected by earth, steel, or thick concrete would die. They would not die immediately, but the most serious cases would succumb within a few hours to 4 or 5 days after exposure. A second group would develop susceptibility to infection due to destruction of their white blood cells and would die from 4 days to 6 weeks after exposure. Another group would incur multiple hemorrhages and die within 2 to 3 weeks from this cause. (See section on Acute Radiation Illness, p. 450.)

Other observed effects of radiation on the human organism include:

(*a*) Surviving women show no present evidence of alteration in reproductivity. Even a dose of radiation ordinarily fatal does not produce sterility in females.

(*b*) Males within a mile of ground zero showed evidence of diminished reproductivity for a period of 3 months, because the reproductive glands are more exposed than in women. The sterilizing dose of radiation in males is very near the fatal dose.

(*c*) Hair loss usually began about 2 weeks after the explosion and was largely restricted to the scalp hair. The survivors have shown regrowth of the hair.

Second Area—One-Half to One Mile

Structural damage due to blast and fire would be general in the area outside the half-mile circle and up to one mile from ground zero. Residential buildings would be almost destroyed. Only fire- and shock-resistant buildings would be immune to any appreciable extent. Casualties from attendant types of injury—flame burns, blast effects, and injuries due to falling debris and flying glass—would consequently be prominent.

Second or third degree flash burns would be suffered by people not protected.

Injury from ionizing radiation also would be serious, but as the distance from the explosion point increases, shielding is more effective in lessening of damage from the rays.

One to One-and-a-Half Miles from Ground Zero

Beyond a mile, blast damage would still be extensive to residential structures. Fire damage would be extensive in inflammable areas.

Flash burns can be expected at this distance. Secondary injuries remain fairly prominent, in the absence of protection by natural or artificial barriers. In the case of Nagasaki, steep hills sharply limited the effects of blast and fire.

Radiation could be expected to be very prominent among the causes of injury up to approximately one-and-a-quarter miles from ground zero. After that distance, such cases drop off sharply.

One-and-a-half to Two Miles from Ground Zero

At Hiroshima the average limit of general structural damage was roughly 2 miles from ground zero. The limits of fire damage would roughly coincide with this boundary, except where wind causes wider effects.

Flash burns will not be so severe in this area.

The number of cases of radiation sickness would decrease markedly in this area, although some at Hiroshima and Nagasaki were reported to have suffered from the rays even at this distance.

Over Two Miles from Explosion Point

Structural damage due to blast and fire is appreciably lessened beyond 2 miles from ground zero and secondary injuries correspondingly decrease. The maximum distance of a recorded structural damage at Hiroshima, however, was 4.1 miles.

Second and third degree flash burns are possible even at this distance, but beyond two and one-half miles the danger apparently disappears.

Radiation injury would be insignificant in this zone.

Residual Radioactivity

The radioactive material deposited from an atomic airburst will vary according to the height at which detonation occurs. In a burst fairly close to the ground, as at Alamogordo, a crater is produced which contains considerable radioactive material, but the contaminated area is quite small.

The Japanese detonations occurred at much higher altitudes and no craters or serious ground-shock resulted. No serious amount of radioactivity remained. Persons who had not been exposed to the blast entered the areas immediately after the detonation in both Japanese explosions and remained for extended periods without incurring radiation injury.

The radioactive elements from such a burst are carried into the stratospheric and substratospheric levels in a circumscribed cloud which rises 30,000 to 60,000 feet and is rapidly diluted with uncon-

taminated air. There may be an *outfall* of radioactive material from this cloud as it moves away with the prevailing winds. This occurred near Nagasaki and detectable amounts of radiation were deposited without evidence of injury to exposed individuals. The possibility of radioactive outfall applies also to explosions closer to the ground.

Effects of Underwater Bomb

An underwater explosion does not create widespread damage from blast effects and heat because of the muffling effects of the water. But in contrast to a high air explosion, residual radioactivity is of considerable concern. The gamma rays and neutrons are virtually all absorbed by the water surrounding the bomb, but the radioactive fission products are carried aloft in the water comprising the column and cloud.

When this column descends, it spreads radioactive materials. Rain from this mist and cloud will also disseminate the dangerous materials over an extensive area, depending on wind direction and velocity. Roughly, the lethal area may extend a half-mile upwind and 2 or more miles downwind. Dangerous concentration would result over a much larger area.

Since radioactive material consists of a number of elements which emit radiation for periods of time varying from fractions of a second to thousands of years, these radioactive elements may injure people through external or internal action.

The elements may produce (*a*) alpha particles that are highly damaging but are unable to penetrate; (*b*) beta particles which are less damaging and only superficially penetrating; or (*c*) gamma rays which are highly penetrating, but relatively the least damaging.

Instruments make it possible to detect the presence of these elements and so prevent external over-exposure to their emitted radiation. However, the possibility remains that an element may be introduced accidentally into the body, lodge there for a period of time and emit radiations which would destroy tissue or induce cancer. People might swallow such elements with food or from contact with hands which have become contaminated. Fortunately, the more dangerous elements such as plutonium are not absorbed to any considerable degree after being swallowed, but are carried off by the bodily processes. People also might get such elements in their bodies through a cut caused by a contaminated instrument or the like. There has been little opportunity to study this problem but apparently there is little danger from these materials.

Atomic Bomb Casualty Commission

No delayed effects of the Japanese atomic bomb explosions have yet been found by the examinations of the Atomic Bomb Casualty Commission of the National Research Council. This AEC-financed study has especially searched for effects which had been anticipated. These studies will continue over a number of years, however, and will be reported upon from time to time. To date, the investigators have found no evidence of increased occurrence of any disease, including cancer.

All available medical records on the survivors of radiation injury, both before and after the atomic bombings in Japan, have been collected. During the last 6 months, the Atomic Bomb Casualty Commission has completed several studies to provide background for future check-ups. Normal blood samples were compared with those of Japanese who received radiation heavy enough to cause their hair to fall out, but no significant differences were found. Another study dealt with intermarriages within families which, including remote cousins may run as high as 25 percent. This study will be of great importance in estimating the effects of atomic bomb blasts on heredity. Another Casualty Commission study deals with fertility among Japanese survivors. Here, as in other cases, investigators are also studying people unaffected by the blasts to provide a check on their findings because earlier medical records on the bomb survivors do not exist. Other studies deal with the growth and development of children and with effects of radiation upon eyesight.

Studies of this general type have been carried out ever since our military forces first moved into Japan at the war's end. Some years will be required to evaluate the findings. Probably it will be 25 years before the first reliable information can be obtained about the hereditary effects of the bomb.

Long-Term Effects of Radiation

In addition to the studies of bomb effects in Japan, the Commission sponsors periodic resurveys of the long-term effects of bomb-radiation at Bikini and Alamogordo. Supplemented by findings at Eniwetok, where the most recent bomb test (May 1948) was held, research at these places will add to the valuable information gained through studies at Hiroshima and Nagasaki.

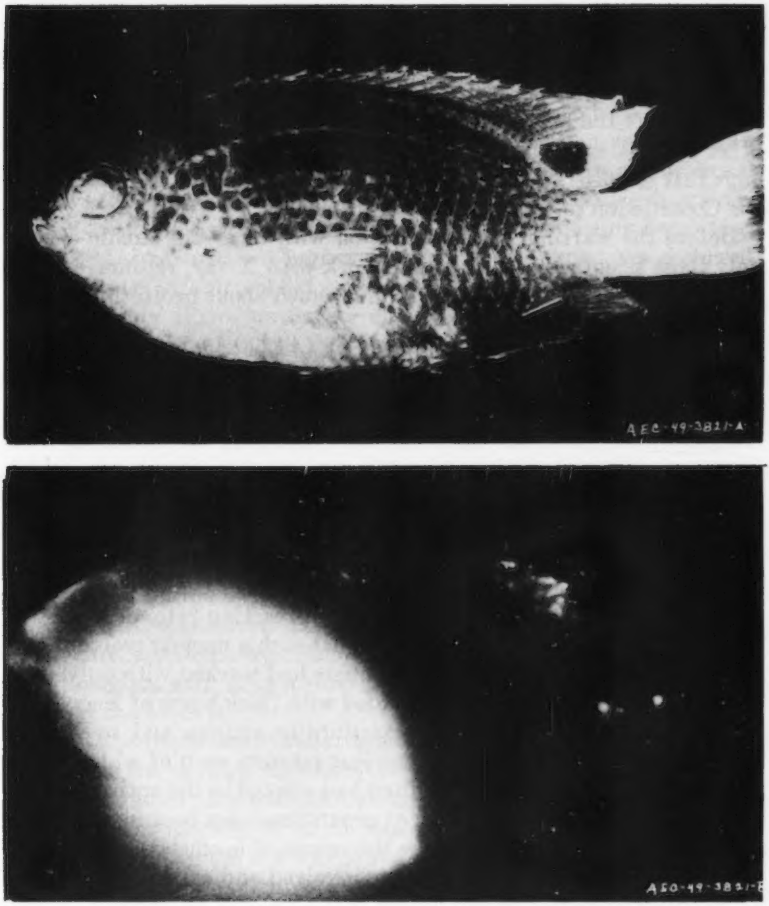
Alamogordo. Briefly, resurveys have found that, at Alamogordo, an area in the New Mexico desert where a bomb was exploded over the earth in July 1945, only the immediate vicinity of the crater remains dangerous. Outside of the fenced-off zone of slightly more than 100

acres that surrounds the crater, there has at no time been evidence of any hazard from external radiation to man, plants, or animals. Wild animals captured this past year in the nearby area outside of the fenced zone appeared to be normal and in good health, and their tissues contained no significant amounts of radioactive material. At the time the last survey was made under a Commission contract by scientific groups from the University of California, Los Angeles, grass and weeds which the bomb burned off were beginning to grow again. A number of range cattle, exposed inadvertently to radioactive dust that scattered after the test blast, are being studied at University of Tennessee but have shown no serious reactions. All 49 calves born to the cows exposed were normal.

Bikini. In the 400 square mile lagoon of lonely Bikini atoll where two bombs were exploded over and under water a year later than at Alamogordo, radioactivity is declining but still is detectable throughout the coral reef that circles the lagoon. External radiation is not dangerous except, perhaps, at the bottom of the lagoon some 200 feet under the surface. Enough radioactive material probably exists to be ultimately dangerous to rats, crabs, and fish if they take the substance into their bodies, or to men if they were to eat for some time the fish from the lagoon or the coconuts from the island's palm trees.

The University of Washington's Applied Fisheries Laboratory made a survey in 1947 and again about a year ago for the Atomic Energy Commission. Investigators took samples of plant and animal life, particularly of fish, clams, oysters, and such creatures off the reefs at depths of 35 to 40 feet. Navy divers took other biological samples at depths up to 200 feet. Scientists recorded the type and weight of samples, then reduced them to ash with electric ovens and acid, and examined tissue residues for radioactivity. Marine plants such as algae and plankton—animals from the size of tiny one-celled protozoon to jelly fish—were also taken and studied.

The scientists found that, in 1948, sand and coral was relatively free of radioactivity. Plants, animals, and fish had gradually accumulated radioactive material, but not enough to cause observable harm to their tissues. They did not accumulate radioactive forms of material more rapidly than they would normal types of the same substance, but because of the scarcity of normal forms of certain elements algae would accumulate trace quantities of radioactive minerals. Fish then fed on algae and plankton; crabs, rats, and birds fed on the fish. and accumulations occurred in this way. When any of these creatures die, the materials were released into the earth or water by decay and once more could recycle through the same chains of food: algae to fish and animals. Roots of palms and pandanus trees, reaching deeply



Damsel fish caught in Bikini lagoon after atomic explosion. Radioautograph made at University of Washington shows how the digestive tract has accumulated radioactive materials picked up in food. Spots on fins show surface contamination.

through the porous earth and coral, tapped brackish water containing radioactive materials and radioactive substances entered the food cycles of animals and birds that fed upon such plants.

The scientists who made the survey expect that this pattern will continue for a considerable period, until the radioactive materials lose their power to radiate, but that the possible hazards to plants and animals will gradually decline. They will make further studies and evaluations of data. Resurveys at Bikini, coupled with laboratory work, will also investigate the genetic effects of radiation.

2. PROTECTION AGAINST RADIATION

The Commission has an overriding responsibility to safeguard people against radiation that originates in atomic production or research. It must protect the health of scientists and workers in Commission and other installations, and of the people who live nearby. All the knowledge that scientists gain in their study of the effects of radiation helps the Commission to assure adequate protection.

Before the wartime experimentation with releasing atomic energy, only those scientists accustomed to work with X-ray, radium, and the few "atom smashers" that existed knew much about protection against radiation.

The first radiation injury—burns from an X-ray—was reported in 1896. It was not until 1915, after many X-ray injuries occurred in hospitals during the war, that the general problem was recognized. And it was 1929 before the National Committee on Radiation Protection, established in the United States, drew up standard methods of radiation protection which were published in a handbook by the National Bureau of Standards. This was the extent of general information in 1942 when, under the concrete West Stands of Stagg Field, University of Chicago stadium, scientists began construction of what was to be the first successful chain-reacting "atomic pile."

At that time, some experts doubted that such a nuclear reactor could be operated safely. Previously, scientists had worked with only small masses of radioactive material shielded with thick boxes of heavy lead. Yet people had died from overexposure to radium and to X-rays. Now it was proposed to operate nuclear reactors each of which would create more powerful radiation than had existed in the entire world.

The fears of these experts proved groundless—not because they overestimated the danger, but because the responsible officials of the Manhattan District recognized the perils involved and called in specialists in radiology and biophysics to apply the knowledge of the past and make sure that the shielding that was built was completely adequate to stop and absorb radiation.

Record of Protection at Installations

Since that time, the health physics, medical and biological programs of the Manhattan Engineer District and of the Atomic Energy Commission and its contractor-operators of plants, have kept ahead of operation problems. The record bears witness to the success of the precautions taken.

Although the dangers from radiation were unprecedented, and although tens of thousands of persons have worked in production and

bomb plants during the last 6 years, very few have suffered from radiation injury. In May 1946, nine persons were exposed in an accident during an experiment on bomb physics. One of these died, two others suffered injuries; the remaining six have apparently escaped unhurt. Several months previously, a similar accident had killed one man. Since May 1946, five persons have suffered injuries, all of them local and much less serious than whole-body radiation. Four of these injuries occurred at one time during the Eniwetok bomb test, May 1948, as related in Chapter II, p. 454. The fifth case occurred during special experiments at Los Alamos and the man has recovered.

An Advisory Board on Safety and Industrial Health, a group of 12 distinguished authorities, appointed by the Commission to survey practices in these fields, reported in 1948: "History affords no parallel to the thorough study of, and protection against, radiation hazards to workers, from inception of the project to the present."

Standard for Safeguards

In establishing its safeguards, the Commission has, whenever possible, adopted and used the standards established by the National Committee on Radiation Protection. The Committee includes representatives from the National Bureau of Standards, the Public Health Service, the Atomic Energy Commission, and from professional groups of radiologists and X-ray workers. Its members are the leading people in these fields.

One of the important standards set by this group established their estimate of the amount of whole-body radiation which a man could tolerate day after day without damage to himself. They knew that a patient who submits to an ordinary chest X-ray received about 2 roentgens during the short time the photograph required; that persons who submit to a complete gastro-intestinal series of X-ray pictures may receive as much as 50 to 75 roentgens to the abdomen.

Studying these records, and those of X-ray technicians, the Committee fixed the *daily permissible dose* of gamma and X-rays for a man at one-tenth of one roentgen, although actually it was estimated a man could stand at least 10 times that much. Thus, the standard permissible dose allowed a safety factor of 10. More recently, experts have made a reestimate and now believe that the safety factor is considerably less than 10—and consequently have recommended that the permissible dose of gamma and X-rays be cut in half—to 5 hundredths of a roentgen a day, or about three-tenths roentgen a week.

However, so broad have been the safety factors established by the Commission and its contractors that, for example, even the 10 workers

who have suffered the greatest exposure to radiation at the Hanford Works, received far less than the new permissible dose. During 1948, at Hanford, the 10 most exposed workers each received a total of 2 roentgens during the entire year—about the amount of a single X-ray of the chest—for a period when the permissible dose, by former standards, would amount to some 30 roentgens and, by the new standards, about 15 roentgens. Thus, the record shows exposures far below the danger point.

The following table gives the average exposure for all workers at Hanford, and for the 10 workers receiving the highest dosage of radiation, throughout the year:

AVERAGE ANNUAL EXPOSURE OF HANFORD WORKERS (IN ROENTGENS)

Year	*All workers*	*Highest ten*
1945	0.9	-------
1946	.6	1.5
1947	.4	1.75
1948	.3	2.0

Record of Protection of the Environment

From the beginning, the national atomic energy industry laid down the principle that its laboratories and plants must so control radiation and radioactive materials that there was no risk of causing injury to people who lived nearby, or to domestic or wild animals in the vicinity.

Two sources of potential danger existed—water and air used to cool nuclear reactors, and industrial wastes.

Coolants. Nuclear reactors, like the engines of airplanes, have to be cooled and the present plants employ immense volumes of air and water to do this job. Since water and air flow through the intense neutron flux of nuclear reactors, they must be cleaned of radioactive materials that might be harmful before they are released again into the rivers and streams, or into the atmosphere.

Wastes. Like many other great industries, the national atomic energy program creates a volume of waste products at its plants and laboratories. They present only one unique problem: Some of them are radioactive. In subsection (*A*) of this chapter, the methods used to make sure they are safely handled are described in some detail.

Results of Protective Measures

Air as a coolant. Release of gases into the atmosphere at Oak Ridge National Laboratory scarcely changes the level of radioactivity in the neighborhood.

The standard that scientists use to measure radioactivity, the *curie*, is based on the work of the famous Curies—Pierre and Eve—who in the early days of the century discovered the radioactive element, radium. From their work stemmed the calculation that, in every gram of radium, some 37 billion atoms are breaking down every second. A curie, then, is that amount of any radioactive material in which some 37 billion atoms break down every second.

But the curie is far too large a measurement to be used in testing radioactivity near Oak Ridge. A *millicurie*, which is *37 million* atomic breakdowns per second, also is too large. So is the *microcurie* which is only *37 thousand* per second. Radioactivity in the neighborhood of Oak Ridge is measured in almost infinitesimal fractions of a microcurie—in hundred-millionths of one microcurie per cubic foot of air.

Very little of the radioactivity that exists there comes from the atomic energy installation. As stated earlier, there is natural radioactivity throughout the world; greater in some spots, less in others. Around Oak Ridge, this natural background radiation is 10 to 100 times greater than the amount released from Oak Ridge operations.

For example, testing of the air about Oak Ridge has shown that this natural radiation is equivalent to the emanations from the breakdown of 40 to 400 radioactive atoms for each cubic foot of air per hour—10 to 100 millionths of a microcurie. To this background radiation, the atomic energy operations add the equivalent of about four breakdowns per cubic foot of air per hour—just one hundred millionth of a microcurie.

To gauge what this means in terms of a cubic foot of air, we must relate the number of breakdowns to the number of atoms in that much air. The scientists estimate that ordinarily there are 1.5×10^{24} atoms in a cubic foot of air, which is 15 with 23 zeros after it—1500 sextillion atoms, or stated another way, one and a half million billion billions of atoms. If each of the atoms of gases in the air were the size of an ordinary pea, there would be enough of them in one cubic foot of air to cover the entire surface of the earth and then pile up, all over the globe, to a depth of rather more than half again as high as the Empire State Building in New York City. Out of this enormous number of atoms in a cubic foot of air, 400 at most become radioactive in an hour in the vicinity of Oak Ridge—a cupful of peas out of enough to deluge the entire earth—and to that amount atomic energy operations contribute just four.

Millions of people have lived all their lives in the midst of a much higher natural radioactivity than this. In the city of Knoxville, for example, background radiation is more than twice as strong as at Oak

Ridge—equivalent to the breakdown of about 1000 radioactive atoms per cubic foot of air per hour. In many districts, notably in the Colorado mountains, the radiation is much higher—10 to 19 times as great—but even there it is insignificant and not considered at all harmful.

It is apparent from these figures that the controls established by the atomic energy industry at Oak Ridge are keeping escaping radioactivity in the air far below any level that might conceivably be considered harmful to people in the vicinity.

Wastes in air. At Hanford, health physicists have given careful consideration to the radioactivity of short-lived gaseous wastes, which are generated during the separation of plutonium after it is removed from nuclear reactors. The amount of such wastes can be reduced by lengthening the time between removal of slugs from the reactor and the start of processing. By increasing the cooling period the radioactivity of one of these waste products may be decreased more than 100 times.

At present, the concentration of these gases in the atmosphere over Richland, Pasco, and Kennewick produces emanations from about 4 atomic breakdowns per hour per cubic foot of air—about the same as at Oak Ridge—which is too little to be a hazard. This problem does not arise at Argonne National Laboratory or at Brookhaven National Laboratory because slugs are not processed there.

Liquid wastes. At Oak Ridge most of the liquid wastes are stored to permit the radioactivity of short-lived products to die. Such products cause most of the radioactivity in the wastes. When the safety point is reached, the liquids pass into a large holding pond, then into White Oak Lake, to White Oak Creek, and ultimately to the Clinch River. All this water system, except the river, is in the Oak Ridge restricted area and repeated careful measurements are made before the water leaves the controlled area.

The standards established require that the total radiation level in White Oak Lake be sufficiently low so that fish which are in the water 24 hours a day will not be harmed. By the time the water reaches Clinch River, even this low degree of radioactivity has been reduced 20 to 1000 times by dilution. Health physicists have observed that the maximum radioactivity added to the water of the Clinch River is about one atom breaking down per cubic centimeter of water per minute. This is considerably lower than the natural radioactive content of many of the most popular mineral waters drunk by people in the United States.

A. RADIOACTIVE WASTES

Laboratory and production operations of the United States atomic energy program create a variety of waste materials which must be disposed of safely. There are two main sources of radioactive wastes:

(*a*) Production plants and nuclear reactors operating at Commission installations. The radioactive wastes from plants and reactors may be gases, liquids, or solids—substances in the air or water that is used to carry away the heat generated in reactors; liquids left over from separating plutonium from other fission products; metal containers and equipment in contact with radiation over long periods.

(*b*) Laboratories and hospitals where radioactive materials are used for research tools or medical treatment. Hospital and laboratories either in treating patients or in experiments generally use small amounts of material with a low level of short-lived radioactivity. The small residues are usually in liquid form and the problem of handling them is minor compared to those at atomic installations.

Limiting Radioactivity in Wastes

In determining the levels of radioactivity permissible in wastes, scientists had to consider the effects both of radiation from outside the body, and of radioactive material taken into the body with food, water, or air. Much smaller quantities of material, much lower rates of radioactivity are dangerous if taken into the body. Since most of the wastes discharged are either released into rivers and streams as liquids or into the air as gas, internal radiation presented the greater problem. The permissible level has been placed safely below any possible danger point.

In setting the level, the problem was less that human drinking water might become contaminated than that people might eat animals that drank water in discharge streams or fish that fed on micro-organisms that had absorbed radioactive material. In protecting against gases, atomic energy installations have guarded against the danger, that, under unusual atmospheric conditions, the radioactive material might be pressed downward and inhaled, or deposited on plants or soil to contaminate vegetation that might be eaten by animals or people.

Scientists also had to consider the particular radioactive materials being discharged in wastes. Those which remain radioactive for thousands of years and are not readily soluble are subject to far dif-

ferent control standards from those which are short-lived and readily dissolved in liquids.

How Wastes are Handled

The Commission has two basic methods for handling radioactive waste materials (*a*) dilution and release, or (*b*) concentration and storage.

Since living things do not normally pick up radioactive forms of a chemical element in preference to nonradioactive forms, high dilution of radioactive material with the same substance in stable form is an excellent safeguard. Reactor operators use this principle when they release radioactive stack gases diluted with large volumes of air.

The Cooling Problem

New coolants are being developed which can be used over and over in a closed system instead of being released into streams or into the air, and when such devices are put into use they will greatly reduce the amount of radioactive materials discharged currently in air and water coolants.

Cooling water. Hanford draws cooling water from the Columbia River and pumps it through the reactors at high velocities. The water is held in a retention basin to permit any radioactivity it may have picked up to die down, and then is discharged back into the river.

Cooling air. At Oak Ridge, cooling air is filtered to remove dust and other particles both before and after use. It is blown through the reactors in great volume and then discharged into the atmosphere through tall stacks. How successful this system has been in giving environmental protection was discussed earlier.

Proper measurement and control of radioactive gases requires a knowledge of local general meteorology and the local climatology of the immediate vicinity. For this purpose, the Commission, in cooperation with the Weather Bureau, has established meteorological observation organizations at Oak Ridge, Hanford, Argonne, and Brookhaven. Brookhaven, when its reactor begins operation, will use air cooling under elaborate safeguards that include an extensive system for measuring and predicting atmospheric conditions.

This laboratory on Long Island has constructed 16 area monitoring stations. Six stations are on laboratory grounds and 10 others are placed up to 12 miles away. They will use automatic equipment of

new design to keep continuous records of radioactivity in the atmosphere. In order to gauge radiation and its effects over a long period, the laboratory will plant corn at each of these monitoring stations. The corn will be of exactly the same strain as that planted at the laboratory itself where the effects of rays from cobalt 60, in various strengths, will be tested. *(Next issue.)* The irradiated corn will serve as a control so that scientists can judge the amount of radiation present at the various scattered plantings. For example, corn a certain distance from the cobalt irradiator might receive 0.2 roentgens in the course of the year. By analyzing the effects upon seed from this corn, scientists can tell whether any of the other scattered plantings of corn also have received as much as 0.2 roentgens of radiation.

Chemical Separation Residues

Liquids. Slugs containing fission products are periodically removed from reactors and processed to recover plutonium. During chemical processing, contaminated materials increase in liquid volume, and hence radioactivity per gallon is reduced step by step. Ultimately, wastes with the highest radioactivity are carefully stored. Wastes containing short-lived materials are temporarily held but, after radioactivity fades out, are discharged. This practice, adopted during the war, is being replaced by even better methods as fast as they can be developed.

Solids. At all installations where radioactivity is encountered, contaminated clothing is laundered and tested before reuse. Contaminated trash and biological specimens are buried or, in some areas, burned in incinerators that do not allow any material to escape. Contaminated equipment, such as motors, valves, piping, is buried. Lead and aluminum shielding is usually decontaminated and used again.

Improved Waste Handling

The atomic energy industry is seeking constantly to reduce the amount of wastes by improving the basic design of equipment. Even when the volume of wastes is reduced to the utmost, however, some waste treatment probably will remain necessary. To meet this need, the Commission is sponsoring research to develop better waste-handling methods. It also supports research upon mechanical, electrical, chemical, and biological methods of concentrating radioactive wastes.

At Commission laboratories, scientists found that various processes that operate naturally to purify water also tend to reduce the intensity of radioactivity when wastes are well diluted. Muds and organisms in ponds and streams absorb and concentrate some radioactive materials. Algae and other aquatic plants can grow in water containing fairly heavy radioactivity and this suggests use of these plants to concentrate long-lived radioactive waste products from the water.

Sanitary engineers suggested that activated sludge such as is used to treat ordinary sewage, might work with radioactive wastes. In effect, organic materials in sewage are eaten by this living sludge which is made up of huge colonies of bacteria. The bacterial cell membranes swell up in water and present an enormous surface area which can hold radioactive material.

Experiments at Los Alamos indicate the sludge may take up more than 95 percent of the long-lived alpha emitter plutonium and this method may prove much less costly than chemical systems to remove radioactive wastes from liquids. However, Los Alamos research men believe that a chemical process may be devised which will remove even more plutonium from wastes—up to 99 percent—and thus reduce the contamination of water far below the limit of safety. Research studies are under way to find out whether similar processes will apply to other types of radioactive materials.

B. HEALTH PHYSICS PROGRAM

The Commission and its contractors have established extensive programs of research not only to explore fully the dangers of radiation to living matter, but also to develop better instruments and methods for detecting radiation, to devise new techniques for handling radioactive materials, and to teach the best methods of working safely with radioisotopes.

The program depends heavily upon all workers in biology and medicine, but the chief responsibility for designing, carrying out, and enforcing safety measures rests upon some 500 health physicists. Of these 10 are broadly trained and the rest are experienced in guarding personnel against radiation and in detecting radiation hazards. Large atomic energy projects employ most of these specialists, and there is a critical need for more, particularly of the broadly trained senior experts. As more and more universities, hospitals, and industries use radioisotopes, the need for trained health physicists will increase enormously.

Health physics groups have been set up by the contractors who operate all atomic energy installations. To protect atomic energy workers and the general public, the health physics organizations maintain staffs of experts to measure radiation, to estimate exposures, and to recommend protective measures.

Types of Protection

The following indicates the kind of protection which the health physicist groups maintain.

Remote Control Techniques

Nuclear reactors and major chemical separation processes are remotely controlled from behind massive shields so that harmful radiation cannot reach the people who operate them. Most maintenance work on reactors and chemical separation equipment is similarly handled, although workers require elaborate protection during replacement of equipment.

Many extremely ingenious devices for remote control manipulation of "hot" materials have been developed both for the laboratory and the production plant. Argonne has put in operation a control device for laboratory use in which the operator, by manipulating his arms and fingers almost as in an ordinary laboratory, can handle radioactive materials and equipment on a bench behind a shield. This almost human device, using electromechanical linkage, is equivalent to lengthening the arms some 8 or 10 feet, and adding a couple of elbows to get around awkward corners in the shielding.

Personnel Monitoring

The health physics group at each site measures the amount of radiation each worker receives when in an area of possible exposure. The worker carries a small pocket ionization chamber and a badge that contains unexposed photographic film. The ionization chambers are read and recorded daily, the film badges are developed once a week.

Results from reading these instruments not only provide daily records of exposure to radiation of each individual worker but also cumulatively provide extremely valuable long-range data that will help in establishing the permissible dose of radiation more exactly.

Analysis of Body Uptake

In experimental work, such as is carried out at Oak Ridge Laboratory, the health physicist must help scientists guard against the

possibility of taking into their bodies dangerous amounts of radioactive material. When it is not possible to provide full protection by using "hot" laboratories, special ventilation and similar devices, the health physicist maintains a constant watch, for example, to make sure that dangerous materials are kept at such low levels of concentration in the air that the worker cannot inhale unsafe quantities.

The health physicist also examines the workers frequently to determine how much radioactive material they may have taken into their bodies. This is usually done by analysis of urine. The analyst must detect extremely small quantities of radioactive isotopes. For example, a man who has dangerous amounts of plutonium in his skeleton will excrete in urine less than one billionth part of one gram of the metal a day. Consequently, the analyst must use extremely sensitive instruments and guard them carefully against accidental disturbances—such as radiation in the instrument itself or in the testing chemicals—and against electrical disturbances that might cause the instruments to give a false register of radioactivity.

The laboratories have worked out satisfactory methods for measuring plutonium and uranium in urine and are developing a similar analysis for certain beta-emitting isotopes of other elements.

Area Monitoring

Health physicists make frequent surveys of intensity and contamination by alpha, beta, gamma, and neutron radiation at the production centers and laboratories. At convenient spots, they also install beta-gamma-sensitive and alpha-sensitive instruments for measuring contamination of worker's hands, feet, nostrils, clothing, and equipment.

Monitors can check a reactor used for producing plutonium more easily than a reactor used in research. In production reactors, operating conditions do not change, and hence radiation will be reduced to negligible intensities. In a research unit, on the other hand, there are several open or partially open ports through which materials are put in or taken out. These may allow radiation to escape and hence make necessary special attention to protect personnel.

The monitors are continually seeking more sensitive means of detecting the presence of minute quantities of radioactive materials. One strange but promising device has come to the attention of biologists at Brookhaven as a byproduct of their radioisotope tracer researches into animal utilization of various rare elements. They have found that the common hornet concentrates barium within its body. (See facing photograph.) It happens that barium is a product of uranium fission. Therefore, they will try placing hornets at key points near the new Brookhaven research reactor to test the possibility

Hornets, such as this one taking a radioactive meal at Brookhaven laboratory, may eventually be used to help health physicists detect harmful radiation. Such "tracer" tests as this have shown that hornets accumulate barium, one of the materials that might leak from a nuclear reactor in radioactive form.

that the insects, by accumulating barium, will serve as indicators of radiobarium leaks long before they could be detected with instruments alone.

The activities of health physicists in monitoring the vicinity of atomic energy installations have been discussed in the section on the handling of wastes, p. 482, *ff*.

Instrument Research

The basic theories on which radiation detection instruments are designed were known and published prior to World War II. However, the sudden creation of a vast new field of atomic energy work required the improvement of existing types of apparatus not only

from the standpoint of performance but also to aid in their manufacture in quantity. Hence research is going forward on instruments designed:

(*a*) To measure fast (high energy) neutron dosages in the presence of gamma radiation, so as to provide greater safety in the operation of nuclear reactors and particle accelerators.

(*b*) To give a reliable count of alpha particles at rates from 5 to 10 per hour so as to permit more accurate analyses of alpha-emitting materials found in waste and body fluids.

(*c*) To give a reliable count of beta particles at rates from 1 to 10 per minute.

(*d*) To accurately monitor personnel for exposure to beta radiation in the presence of soft gamma radiation or vice versa.

Designers also will seek to devise instruments for measuring, with sufficient sensitivity for health monitoring, contamination of the atmosphere by such low-energy beta-emitting isotopes as carbon 14 and sulfur 35, now being distributed in considerable quantities for research; for better detection and measurement of radioactive materials in the atmosphere; and for separately and continuously monitoring gamma, beta, and alpha-emitting materials in water. They will work also to improve the stability, ease of maintenance, and accuracy of health physics instruments now in use.

Teams to Handle Emergencies

Nuclear reactors are highly stable in operation, but health physicists must take precautions against emergencies that might cause them to emit damaging amounts of radiation, as for example, in severe earthquakes. In such an occurrence, plans must be ready to evacuate all employees promptly. Health physics personnel at major installations maintain a 24-hour radio-equipped emergency service and have developed emergency procedures. The Commission also is organizing "emergency teams" at the major installations.

Research in Health Physics

Protection of personnel depends on knowing accurately the amount of radiation they absorb. One of the most important immediate problems of health physics is better determination of dosages for several types of radiations, particularly of neutrons of various en-

ergies. The roentgen, ordinarily the unit for measuring radiant energy, depends for its count on the number of ions caused by the radiation. But this is tricky with neutrons, because the ionization they cause is indirect.

In air, for example, a neutron first ionizes an atom of nitrogen or oxygen by direct impact. The fragments, in turn, ionize other atoms. In living tissue under the impact of neutrons, protons impelled by the particles are the principal ionizing bodies. Research men are seeking a completely satisfactory method to relate neutron dosage to measurements for other types of radiation.

Experiments during the last 7 years have indicated that neutrons are more damaging than gamma- or X-rays to living things, and the National Committee on Radiation Protection will probably recommend an additional safety factor of 10 as the permissible exposure to neutrons. The recommended permissible limit of exposure to beta rays will probably be the same as for gamma- and X-rays. Alpha-emitting radioisotopes that may become deposited in the body are probably 10 to 20 times more harmful than gamma- or X-rays, or beta particles and the Committee will take this into account in its recommendation. Factors of safety of 5 for neutrons and 10 for alphas have been used since the atomic energy project began.

In order to give data that will aid in establishing realistic permissible levels of radiation, large numbers of animals have been exposed to X-rays and other external radiations at Argonne, Oak Ridge, Rochester, the National Cancer Institute, Columbia University, and the Biochemical Research Foundation. The purpose is to look for possible subtle, long-time harmful effects of radiation, such as shortening of life-span.

Research in Poisonous Materials

Of utmost importance in giving full protection to all who come in contact with the materials used or produced by the national atomic energy program is the best possible understanding of the toxic effects of some of these materials. Laboratories have considerable research under way on the toxicity and other effects of plutonium and beryllium.

Plutonium Toxicity

Many heavy metals, such as lead, radium, and mercury, accumulate in the bones and interfere with the body's blood-forming mechanism. Lead and mercury are chemically poisonous, but radium also gives off destructive alpha particles and gamma rays. Many people have died

from radium poisoning in the past. Many people still suffer today from the effects of radium taken into the body many years ago. People have died from ingesting less than one twenty-millionth of one ounce of radium.

The man-made fissionable material plutonium is probably more dangerous than radium. The University of Chicago Metallurgical Laboratory—more recently the Argonne Laboratory—has studied plutonium poisoning extensively to develop possible courses of treatment in case of accident.

Like radium. In experimental animals plutonium acts very much like radium. If lodged in the tissues of the body, it will remain for years and may cause severe blood disorders, bone lesions, or even tumors.

In the experimental animal, plutonium salts that enter the blood stream become quickly distributed throughout the body. Within 24 hours, most of the plutonium is concentrated in the skeleton. Within a week, the skeleton has about three-fourths of all the body plutonium, and retains it indefinitely.

When very small amounts of plutonium dust were inhaled by rats, every animal developed radiation pneumonia. Many eventually died with tumors of the lung, quite similar to cancer of the lung in man, and some from bone cancer or liver disease. Plutonium deposited under the skin of mice may cause ulcer of the skin or turn the hair gray or, after a long interval, induce malignant skin tumors.

Scientists believe that if a man should accidentally absorb plutonium in the course of his work, he would suffer in a very similar way.

Treatment. Scientists never found a satisfactory way to remove radium from the body, but the Argonne workers have had some success with plutonium. They have discovered that a single dose of zirconium, a nontoxic and nonradioactive metal, if administered within an hour after injection of plutonium, alters the normal behavior of plutonium in laboratory animals. Within minutes, practically all the plutonium leaves the blood and is eliminated through the kidneys. When zirconium is administered 3 days after absorption of plutonium, the amount of plutonium excreted in the urine is increased 50-fold. For at least 10 days following cessation of zirconium treatment, animals continue to eliminate about three times as much as the normal excretion of plutonium.

Zirconium treatment is effective even when plutonium has remained in the body for long periods. An animal treated with zirconium 2½ years after it had received plutonium showed a marked increase in the rate of elimination of plutonium. Zirconium also is

effective against some other radioactive elements, but does not affect radium and radiostrontium.

Beryllium Poisoning

Atomic production centers and laboratories use many materials not hitherto known in industry, which are not radioactive but which can poison those who work with them unless adequate safeguards are maintained. One such material is beryllium, the fourth lightest of all the elements.

Since the 1920's, beryllium has been used in this country in alloys with nickel, aluminum, and copper because of its great lightness and resistance to stress and heat. In the late 1930's, scientists developed a powder containing beryllium as well as zinc, manganese, and silica, which fluoresced when exposed to ultraviolet light. From this grew the huge fluorescent lamp industry. Physicists, knowing that beryllium emits neutrons when bombarded with alpha particles, used it as a tool in atomic energy research.

Between 1933 and 1942, European physicians described illness in workers handling beryllium compounds, chiefly a disease of the lungs that sometimes resulted in death. In 1943, similar illness first appeared in the United States and the Manhattan District began to investigate protection of its workers.

Plants extracting beryllium from the ore have the greatest number of cases of beryllium poisoning, especially a serious skin irritation, eye infection, or difficulty in healing of wounds. Such wounds received much public attention in 1949, when news stories were published about children who cut their hands playing with fragments of discarded fluorescent lamps. The inner coating of such lamps contained beryllium.

When inhaled. Irritation of the nose and throat by beryllium may be the first step in the development of bronchitis or a chemical pneumonia, if the victim continues to work with beryllium. Several deaths have been reported in industry from pneumonitis caused in this way, but immediate removal of workers, hospital care, and oxygen treatment have now made fatalities very rare.

Extremely small amounts of beryllium in the air are sufficient to cause the disease in some individuals. To measure these quantities, very delicate chemical and spectrographic methods have been developed at the University of Rochester, the Kettering Laboratory of the University of Cincinnati, and the Trudeau Foundation, Saranac Lake, New York. The Rochester Project has made several on and off-site air surveys in the vicinity of beryllium refining plants in order to relate actual conditions with the onset of the disease. Engineering methods

have been developed to reduce to the vanishing point the amount of beryllium in the workers' breathing zone.

Chronic disease. In a group of clinical cases, certain beryllium compounds absorbed in fantastically small amounts over a period of time caused chronic beryllium poisoning. Patients are ill about 3 years, few recover completely, and about one in five patients dies. Such cases have occurred in beryllium extraction and fluorescent lamp plants, in brass plants using copper-beryllium alloys; in Government laboratories, and among a small number of people who live near beryllium plants.

The most striking feature of chronic beryllium poisoning is a delay, sometimes as long as 10 years, between exposure and the onset of symptoms. Physicians may easily confuse chronic beryllium disease with miliary tuberculosis. The patient shows great loss of weight, coughs, and has shortness of breath. A chest X-ray will indicate damage much like that in certain forms of tuberculosis. Chronic beryllium poisoning may also involve lymph nodes, liver, spleen, lung, skin, and probably bone.

Individuals react very differently to beryllium. In one group of exposed workers only 4 percent became sick enough to come to the attention of a physician.

No treatment exists for chronic beryllium poisoning except oxygen, nursing and careful medical supervision. With this care, the patient may regain a reasonable degree of health, much as in tuberculosis.

Treatment studies. In 1946, the first case of chronic beryllium poisoning was reported on an atomic energy project. Since 1947, several other patients, including research and metallurgical workers, have been reported from Commission-sponsored activities. Laboratory workers now handle beryllium on a minute scale in special equipment enclosed to prevent contamination of the air.

Scientists and physicians who conducted clinical studies of chronic beryllium poisoning cases have made their findings available to the medical profession. Radioactive beryllium (beryllium 7), produced in a cyclotron, has made it possible for workers in hospitals, medical schools, and Commission laboratories to trace the effects of small amounts of beryllium on body metabolism.

A committee of trained Commission and contractor personnel is formulating recommendations for medical and engineering control of the toxic effects of beryllium. This group meets at regular intervals to review data and prepare reports for projects handling beryllium compounds. This assistance also is made available to those responsible for the health of workers in industry.

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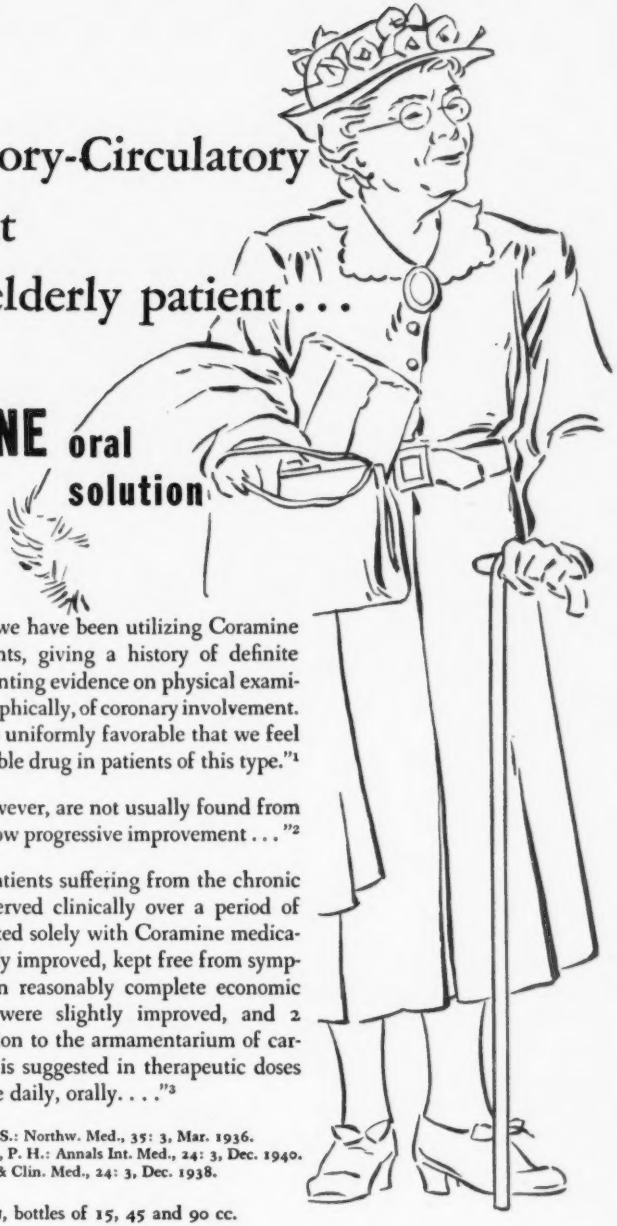

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